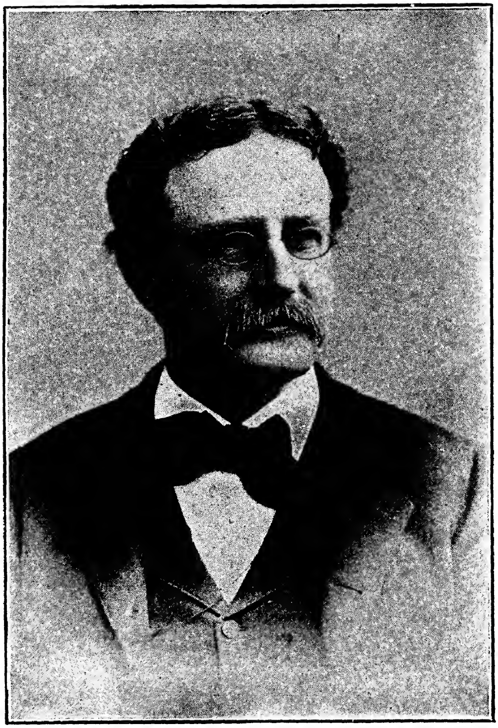

THOMAS M. DROWN, M.D., LL.D.

See Biographical Notice, p. 288.

TRANSACTIONS

OF THE

AMERICAN INSTITUTE OF MINING ENGINEERS.

VOL. XXXVI.

CONTAINING THE PAPERS AND DISCUSSIONS OF 1905.

NEW YORK CITY:
PUBLISHED BY THE INSTITUTE,
AT THE OFFICE OF THE SECRETARY.
1906.

PREFACE.

THIS volume contains all the published proceedings, papers and discussions of 1905, with the following exceptions:—

1. Certain contributions received after January 1, 1905, yet sufficiently early to be included in Volume XXXV., then in press, were published in that volume, instead of this, because they discussed papers contained in Volume XXXV.

2. Certain valuable papers, presented to the Iron and Steel Institute, in connection with its New York meeting of October, 1904, and, under a friendly agreement between the Councils of the two Institutes, available for publication by this Institute, were thus published in the *Bi-Monthly Bulletin*,* but have been necessarily omitted from this volume for lack of space.

3. Two important and interesting addresses delivered at the Washington meeting, February, 1905.†

4. Brief obituaries of Members and Associates reported as deceased in 1904.‡

5. Library reports and other announcements of general but temporary interest to members.

Of the above classes, the *Bi-Monthly Bulletin* furnished to members about 500 pages of valuable material, which it would have been impossible to include in the annual volume of *Transactions.*

On the other hand, certain contributions received since January 1, 1906, but offered in discussion of papers contained in this volume, have been here included, for the convenience of readers, instead of being held over for Volume XXXVII.

* "Acid Open-Hearth Manipulation," by Andrew McWilliams and William H. Hatfield, *Bulletin* for March. 1905, p. 279; "Comparison of Methods for the Determination of Carbon and Phosphorus in Steel," by Baron von Jonstorff, Andrew A. Blair, Gunnar Dillner and J. E. Stead, *ib.*, p. 289; "The Development and Use of High-Speed Tool-Steel," by J. M. Gledhill, *ib.*, p. 537.

† "Address of Welcome to the U. S. National Museum," by Richard Rathbun, Assistant Secretary of the Smithsonian Institution, *Bi-Monthly Bulletin*, July, 1905, p. 923; "The Division of Applied Geology of the U. S National Museum," by Dr. George P Merrill, Curator, *ib.*, p. 929.

‡ *Bi-Monthly Bulletin* for July, 1905, p. 761.

For the regular appearance of the *Bulletin*, and the prompt publication of this volume, I have to give the credit once more, as in the two last years, to the intelligent and assiduous labors of Dr. Joseph Struthers, Assistant Secretary and Editor.

R. W. Raymond.

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DISCUSSIONS

OFFICERS.

For the year ending February, 1906.

COUNCIL.*

PRESIDENT OF THE COUNCIL.

JAMES GAYLEY.

VICE-PRESIDENTS OF THE COUNCIL.

GEORGE W. MAYNARD.......................................NEW YORK, N. Y.
JULIAN KENNEDY.......................................PITTSBURG, PA.
CHARLES D WALCOTT.......................................WASHINGTON, D. C.

(Term expires February, 1906)

WILLIAM P. BLAKE.......................................TUCSON, ARIZ.
THOMAS F. COLE.......................................DULUTH, MINN.
IRVING A. STEARNS.......................................WILKES-BARRE, PA.

(Term expires February, 1907)

COUNCILORS.

FRANK KLEPETKO.......................................NEW YORK, N. Y.
BENJAMIN B LAWRENCE.......................................NEW YORK, N. Y.
HEINRICH RIES.......................................ITHACA, N. Y.

(Term expires February, 1906)

F. L GRAMMER.......................................BALTIMORE, MD.
JOSEPH HARTSHORNE.......................................POTTSTOWN, PA.
CHARLES H. SNOW.......................................NEW YORK, N. Y.

(Term expires February, 1907)

A. A. BLOW.......................................DENVER, COLO.
FRANK LYMAN.......................................NEW YORK, N. Y.
T. A. RICKARD.......................................NEW YORK, N. Y.

(Term expires February, 1908)

SECRETARY OF THE COUNCIL.

R. W. RAYMOND.......................................NEW YORK, N. Y

(Term expires February 1906)

CORPORATION.

JAMES GAYLEY, President; R. W. RAYMOND, Secretary,
FRANK LYMAN, Treasurer.

DIRECTORS

T A. RICKARD, CHARLES H SNOW, R. W. RAYMOND

(Term expires February, 1906)

JAMES GAYLEY, FRANK KLEPETKO, FRANK LYMAN.

(Term expires February, 1907)

JAMES DOUGLAS, JAMES F. KEMP, ALBERT R. LEDOUX.

(Term expires February, 1908)

Consulting Attorneys, Blair & Rudd, New York, N. Y.

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* SECRETARY'S NOTE.—The Council is the professional body, having charge of the election of members, the holding of meetings (except business meetings), and the publication of papers, proceedings, etc. The Board of Directors is the body legally responsible for the business management of the Corporation, and is therefore, for convenience, composed of members residing in New York.

POSTSCRIPT.

The list of officers on the preceding page is that of the year 1905, which is the period covered by the contents of this volume. But the result of the elections held at the Annual Meeting of February, 1906, although strictly belonging to the next volume, is here reported for the convenience of members.

The following officers were elected at the Annual Meeting, February 20, 1906:—

COUNCIL.

PRESIDENT: Robert W. Hunt.

VICE-PRESIDENTS: *For two years,* Henry M. Howe, J. B Grant, James D. Hague.

SECRETARY: R W. Raymond.

COUNCILORS: *For three years,* Theodore Dwight, Walter Wood, Wm. Fleet Robertson.

CORPORATION.

PRESIDENT: James Gayley.

VICE-PRESIDENT: James Douglas.

SECRETARY: R. W. Raymond.

TREASURER: Frank Lyman.

DIRECTORS: *For three years,* Theodore Dwight, Charles H. Snow, R. W Raymond.

PAST OFFICERS.

Presidents.

*David Thomas 1871
R. W. Raymond 1872
R. W. Raymond 1873
R. W. Raymond 1874
*A. L. Holley 1875
*Abram S. Hewitt 1876
*T. Sterry Hunt 1877
*Eckley B. Coxe 1878
*Eckley B. Coxe 1879
*William P. Shinn 1880
William Metcalf 1881
*Richard P. Rothwell 1882
Robert W. Hunt 1883
James C. Bayles 1884
James C. Bayles 1885
Robert H. Richards 1886
*Thomas Egleston 1887
William B. Potter 1888
Richard Pearce 1889
*Abram S. Hewitt 1890
John Birkinbine 1891
John Birkinbine 1892
H. M. Howe 1893
John Fritz 1894
*J. D. Weeks 1895
E G. Spilsbury 1896
*Thomas M. Drown 1897
C. Kirchhoff 1898
James Douglas 1899
James Douglas 1900
E. E. Olcott 1901
E. E. Olcott 1902
Albert R Ledoux 1903
Albert R. Ledoux 1904

Secretaries.

*Martin Coryell 1871–1872
*Thomas M. Drown 1873–1884
R. W. Raymond .... 1884 ——

Treasurers.

J. Pryor Williamson 1871–1872
*Theodore D. Rand 1872–1903
Frank Lyman .... 1903 ——

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* Deceased.

HONORARY MEMBERS.

Prof. Richard Åkerman	Stockholm, Sweden.
Andrew Carnegie	New York, N. Y.
Prof. Hans Hoefer	Leoben, Austria.
Prof. Haton de la Goupillière	Pau, Basses, Pyrénées, France.
Prof. Henri Louis Le Chatelier	Paris, France.
M. Floris Osmond	Paris, France.
Prof. Dimitry Constantin Tschernoff	St. Petersburg, Russia.
Prof. Dr. Hermann Wedding	Berlin, Germany.

Honorary Members (*Deceased*).

Bell, Sir Lowthian	1904
Castillo, A. Del	1895
Contreras, Manuel Maria	1902
Daubrée, A.	1896
Drown, Thomas M.	1904
Gaetzschmann, Moritz	1895
Gruner, L.	1883
Hunt, T. Sterry	1892
Kerl, Bruno	1905
Le Conte, Joseph	1901
Lesley, J. P.	1896
Patera, Adolph	1890
Percy, John	1889
Posepny, Franz	1895
Richter, Theodor	1898
Roberts-Austen, W. C.	1902
Serlo, Albert	1898
Siemens, C. Williams	1883
Thomas, David	1882
Tunner, Peter R. von	1897

LIST OF THE MEETINGS OF THE INSTITUTE AND THEIR LOCALITIES FROM ITS ORGANIZATION TO OCTOBER, 1904.

Number.	Place.	Date.	Transactions. Vol.	Page
I.	Wilkes-Barre, Pa.*	May, 1871	i.	3
II.	Bethlehem, Pa.	August, 1871	i.	10
III.	Troy, N. Y.	November, 1871	i.	13
IV.	Philadelphia, Pa.	February, 1872	i.	17
V.	New York, N. Y.*	May, 1872	i.	20
VI.	Pittsburg, Pa.	October, 1872	i.	25
VII.	Boston, Mass.	February, 1873	i.	28
VIII.	Philadelphia, Pa.*	May, 1873	ii.	3
IX.	Easton, Pa.	October, 1873	ii.	7
X.	New York, N Y.	February, 1874	ii.	11
XI.	St. Louis, Mo.*	May, 1874	iii.	3
XII.	Hazleton, Pa.	October, 1874	iii.	8
XIII.	New Haven, Conn	February, 1875	iii.	15
XIV.	Dover, N. J.*	May, 1875	iv.	3
XV.	Cleveland, O.	October, 1875	iv.	9
XVI.	Washington, D. C	February, 1876	iv.	18
XVII.	Philadelphia, Pa.†	June, 1876,	v.	3
XVIII.	Philadelphia, Pa	October, 1876	v.	19
XIX.	New York, N. Y.	February, 1877	v.	27
XX.	Wilkes-Barre, Pa.*	May, 1877	vi.	3
XXI.	Amenia, N. Y.	October, 1877	vi.	10
XXII.	Philadelphia, Pa	February, 1878	vi.	18
XXIII.	Chattanooga, Tenn *	May, 1878	vii.	3
XXIV.	Lake George, N Y.	October, 1878	vii.	103
XXV.	Baltimore, Md *	February, 1879.	vii.	217
XXVI.	Pittsburg, Pa.	May, 1879	viii.	3
XXVII.	Montreal, Canada	September, 1879	viii	121
XXVIII.	New York, N. Y *.	February, 1880	viii.	275
XXIX.	Lake Superior, Mich.	August, 1880	ix.	1
XXX.	Philadelphia, Pa *.	February, 1881	ix.	275
XXXI.	Staunton, Va.	May, 1881.	x.	1
XXXII.	Harrisburg, Pa.	October, 1881	x.	119
XXXIII.	Washington, D. C.*	February, 1882	x.	225
XXXIV.	Denver, Col	August, 1882	xi.	1
XXXV.	Boston, Mass.*	February, 1883	xi.	217
XXXVI.	Roanoke, Va.	June, 1883	xii.	3
XXXVII.	Troy, N. Y.	October, 1883	xii.	175
XXXVIII.	Cincinnati, O.*	February, 1884	xii.	447
XXXIX.	Chicago, Ill.	May, 1884	xiii.	1
XL.	Philadelphia, Pa.	September, 1884	xiii.	285
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XLII.	Chattanooga, Tenn	May, 1885	xiv.	1

* Annual meeting for the election of officers The rules were amended at the Chattanooga meeting, May, 1878, changing the annual election from May to February

† Begun in May at Easton, Pa , for the election of officers, and adjourned to Philadelphia.

Number.	Place	Date.	Transactions. Vol	Page
XLIII.	Halifax, N. S.	September, 1885	xiv.	307
XLIV.	Pittsburg, Pa.*	February, 1886	xiv.	587
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XLVI.	St. Louis, Mo	October, 1886	xv.	lxx.
XLVII.	Scranton, Pa.*	February, 1887	xv.	lxxvii.
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LV.	Ottåwa, Canada	October, 1889	xviii.	xxiv.
LVI.	Washington, D. C *	February, 1890	xviii.	xxx.
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LIX.	Cleveland, O	June, 1891	xx.	xvi.
LX.	Glen Summit, Pa	October, 1891	xx.	lxi.
LXI.	Baltimore, Md.*	February, 1892	xxi.	xix.
LXII.	Plattsburgh, N. Y	June, 1892	xxi.	xxxiii.
LXIII	Reading, Pa	October, 1892.	xxi.	xliv.
LXIV.	Montreal, Canada*	February, 1893	xxi.	lii.
LXV.	Chicago, Ill	August, 1893	xxii.	xiii.
LXVI.	Virginia Beach, Va *.	February, 1894	xxiv.	xvii.
LXVII	Bridgeport, Conn	October, 1894	xxiv.	xxxv.
LXVIII	Florida†	March, 1895	xxv.	xix.
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LXX.	Pittsburg, Pa.*	February, 1896	xxvi.	xvii.
LXXI.	Colorado	September, 1896	xxvi.	xxix.
LXXII.	Chicago, Ill	February, 1897	xxvii.	xvii.
LXXIII	Lake Superior	July, 1897	xxvii.	xxx.
LXXIV.	Atlantic City, N. J.*	February, 1898	xxviii.	xvii.
LXXV.	Buffalo, N. Y.	October, 1898	xxviii.	xxxvi.
LXXVI.	New York City*	February, 1899	xxix.	xvii.
LXXVII.	California	September, 1899	xxix.	xlix.
LXXVIII.	Washington, D. C.*	February, 1900	xxx.	xix.
LXXIX.	Canada	August, 1900.	xxx.	xlv.
LXXX	Richmond, Va.*	February, 1901	xxxi.	xix.
LXXXI.	Mexico	November, 1901	xxxi and xxxii.	cxviii.
LXXXII.	Philadelphia, Pa.‡	May, 1902	xxxiii., xxi and	xxxv.
LXXXIII.	New Haven, Conn	October, 1902	xxxiii.	xlvii.
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LXXXVIII	Washington, D. C	May, 1905	xxxvi.	xlii.
LXXXIX.	British Columbia	July, 1905	xxxvi.	liii.

* Annual meeting for the election of officers.

† Begun in February at New York City, for the election of officers, and adjourned to Florida.

‡ " " " " " " " " " " " " " to Philadelphia.

PUBLICATIONS.

THE publications of the Institute comprise:

TRANSACTIONS.

The volumes of *Transactions*, which are published annually, contain the list of officers, rules, etc., the Proceedings, and the papers revised for final publication. (In this revision, after the preliminary publication, authors are permitted to use the largest liberty; and the changes and additions made in papers are sometimes important. It should be borne in mind by those who study or quote a paper in the preliminary edition, that they may not have in that form the ultimate and deliberate expression of the author's views. It should be added, however, that in the majority of cases there are no important changes.) These volumes are for sale as follows, in paper covers:

Vols. I. to IV., inclusive, each, ...	$3.00
Vols. V. to VIII., inclusive, each, ...	4.00
Vols. IX. and X. (a small supply only on hand), each, .	10.00
Vols. XI. to XXIX., inclusive, each, ...	5.00
Vols. XXX. and XXXI., each, ...	6.00
Vol. XXXII., ...	5.00
Vols. XXXIII. to XXXVI., inclusive, each, ...	6.00

Half-morocco binding, $1 extra per volume.

Complete set of *Transactions*, Vols. I. to XXXVI., inclusive, half-morocco binding (freight prepaid), ... 220.00

INDEXES AND SPECIAL EDITIONS.

Index, Vols. XVI. to XX., inclusive, paper, ...	$1.00
Index, Vols. XXI. to XXV., inclusive, cloth, ...	1.25
Index, Vols. XXVI. to XXX., inclusive, cloth, ...	1.50
The last, in half-morocco binding, ...	2.50

"*The Genesis of Ore-Deposits*," comprising the famous treatise of the late Professor Franz Posepny, with the successive discussions thereof by Le Conte, Blake, Winchell, Church, Emmons, Becker, Cazin, Rickard and Raymond (all of which were published in Volumes XXIII. and XXIV. of the *Transactions* of the Institute, and subsequently in the special "Posepny Volume," issued by the Institute); also, later papers by Van Hise, Emmons, Weed, Lindgren, Vogt, Kemp, Blake, Rickard and others, and the discussions of these papers by De Launay, Beck, and many others (some of these were included in Volume XXX. and the remainder appeared in Volume XXXI.); also a complete bibliography of the Institute papers and discussions on this subject from 1871 to the present time.

The original Posepny volume comprised 265 pages, and was sold for $2.50, at which price the edition was long since exhausted. The present volume is an octavo of 825 pages, bound in "book-linen," of the same color as the standard binding of the *Transactions*, . . . $6.00

Half-morocco bound copies, ... 7.00

"*The Evolution of Mine-Surveying Instruments.*" This is a volume of about 400 pages, issued in the same style as the foregoing, and containing the original paper of Mr. Dunbar D. Scott on that subject (*Transactions*, XXVIII.), first published in 1898, together with later papers, continuing the same subject, and discussions thereof, by Hoskold, Lyman, Davis and many others, . 3.50

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Spanish-American Mining and Metallurgical Glossary, bound in leather, pocket-size, 96 pages, ... 0.75

Special Mining and Railway Map of Mexico, size 14 by 20, prepared by order of Dept. of Fomento, 1901, . . . 0.35

List of Members, Rules, etc., paper, ... 0.50

Bi-Monthly Bulletin, paper (each), ... 2.00

PAMPHLETS.

1. The Minutes of the Proceedings of each Meeting.

2. Such of the papers presented or read by title at each Meeting as are furnished by the authors and approved by the Council for full publication. (In nearly all cases in which papers, the titles of which appear in the Proceedings, are not subsequently published, they have been withdrawn by the authors.) These papers are published separately in pamphlet form, and are marked "subject to revision." Beyond the edition distributed, without charge, to members and associates not in arrears, a small supply is retained to meet subsequent demand. There are no copies on hand of papers read before 1880. The stock is nearly complete from 1880. These papers are for sale at the office of the Secretary, or are sent to purchasers by mail or express, charges paid, on receipt of the price, as follows:

No of Pages.	Single Copies.	10 Copies.	20 Copies.
8 or less	$0 10	$0 60	$1 00
9 to 12 inclusive	0 10	0 80	1 40
13 to 16 "	0 12	1 00	1 75
17 to 20 "	0 16	1 25	2 25
21 to 24 "	0 20	1 50	2 75
25 to 40 "	0 25	2 00	3 50
41 to 56 "	0 30	2 50	4 50
57 to 72 "	0 35	3 00	5 00
73 to 88 "	0 40	3 25	5 25
89 to 104 "	0 45	3 50	6 00
105 to 120 "	0 50	3 75	6 25

Papers with folders and inserted plates subject to special price

Authors' Edition of Pamphlets.

Extra copies, if ordered before the printing of the pamphlet edition for distribution to the members of the Institute, will be furnished to authors, under Rule VII., at special rates, which will be stated on application to the Secretary, R. W. Raymond, 99 John St., New York, N. Y. (P. O. Box 223).

THE INCORPORATION OF THE INSTITUTE.

A general meeting of Members and Associates, held December 29, 1904, upon notice duly given according to law, adopted by unanimous vote a resolution authorizing the incorporation of the Institute under the Membership Corporations Act of the State of New York, and with the name of "American Institute of Mining Engineers," by the following persons, to wit: James Douglas, James Gayley, James F. Kemp, Frank Klepetko, Albert R. Ledoux, Frank Lyman, R. W. Raymond, T. A. Rickard and Charles H. Snow, and authorizing the said incorporators to adopt a Constitution and By-Laws for the Institute.

This incorporation was completed January 9, 1905; and at a meeting of the incorporators, acting as the Board of Directors, a Constitution and By-Laws were adopted, to be presented for final adoption at the first annual meeting of the corporation.

At this meeting, held February 21, 1905, the following Constitution and By-Laws were read in full, and unanimously adopted by a vote of all members present in person or by proxy:

CONSTITUTION.

[ADOPTED FEBRUARY 21, 1905.]

ARTICLE I.

NAME AND OBJECT.

SEC. 1. This Institute is incorporated under the Membership Corporation Law of the State of New York; its corporate name is AMERICAN INSTITUTE OF MINING ENGINEERS; and its objects are such as are stated in its Certificate of Incorporation.

ARTICLE II.

MEMBERS.

SEC. 1. The membership of the Institute shall comprise four classes, namely: (1) Members; (2) Honorary Members; (3) Associates; and (4) Honorary Associates. Only Members and Associates residing within the United States of America, Republic of Mexico and Dominion of Canada shall be entitled to vote at the meetings of the Institute.

SEC. 2. All Members, Honorary Members, Associates and Honorary Associates of the American Institute of Mining Engineers as the same existed on the day of the incorporation of this Institute, are Members, Honorary Members, Associates and Honorary Associates, respectively, of this Corporation.

SEC. 3. The following classes of persons shall be eligible for membership in the Institute, namely: as Members and Honorary Members, all professional mining engineers, geologists, metallurgists or chemists, and all persons practically engaged in mining, metallurgy or metallurgical engineering; as Associates and Honorary Associates, all persons desirous of being connected with the Institute who, in the opinion of the Council, are suitable.

SEC. 4. Every candidate for election as a Member or Associate of the Institute must be proposed for election by at least three Members or Associates; must be approved by the Committee on Membership, as prescribed in the By-Laws; and must be elected by the Council. Not less than three-fourths of the votes cast shall be necessary to an election. Every person so elected shall become a Member or Associate, as the case may be, upon payment of his first dues as hereinafter prescribed. Each candidate for Honorary Member or Honorary Associate, must be recommended by at least ten Members or Associates; must be approved by the Council; and must be elected by ballot at a meeting of the Board of Directors by the unanimous vote of all the Directors present; provided, however, that the number of Honorary Members and Honorary Associates shall not at any time exceed twenty.

SEC. 5. If any person elected a Member or Associate does not, within sixty days after notice of his election, accept the same and pay his initiation fee and dues for the current year, his election may be cancelled at the discretion of the Council.

SEC. 6. The Council may at any time change the classification of a person elected as an Associate so as to make him a Member, or vice versa. All Members and Associates shall be equally entitled to the privileges of membership, provided that Honorary Members, Honorary Associates, and Members and Associates whose Post-Office addresses shall be outside of the United States, Mexico and Canada, shall not be entitled to vote.

ARTICLE III.

DUES.

SEC. 1. The dues of Members and Associates shall be Ten Dollars per annum, payable in advance on the first day of each Calendar year. Each newly elected Member or Associate shall pay, when notified of election, an initiation fee of Ten Dollars in addition to the dues for the current year. Honorary Members and Honorary Associates shall not be liable to initiation fee or dues. Any Member or Associate in arrears for one year may, at the discretion of the Council, be deprived of the receipt of publications or stricken from the list of Members, provided that he may be restored to membership by the Council on payment of all arrears or may be again proposed and elected after an interval of three years

SEC. 2. Any Member or Associate not in arrears may become, by the payment of One Hundred and Fifty Dollars at one time, a Life Member or Associate; and shall not be liable thereafter to annual dues.

ARTICLE IV.

BUSINESS MEETINGS OF THE INSTITUTE.

SEC. 1. The annual meeting of the Institute for the election of Directors and transaction of other business shall take place on the third Tuesday in February in each year. A report of the financial condition of the Institute and an abstract of the accounts shall be furnished by the Directors, and presented at each annual meeting.

SEC. 2. Special business meetings of the Institute may be held at such times and places as the Board of Directors may appoint, upon notice to all Members and Associates entitled to vote, directed to each at his last known Post-Office address, and mailed in the City of New York not less than twenty days before the date fixed for such meeting.

SEC. 3. At all business meetings of the Institute the presence of nine Members and Associates shall constitute a quorum.

SEC. 4. At all business meetings of the Institute Members and Associates may vote either in person or by proxy, but no Member or Associate in arrears since the last annual meeting shall be entitled to vote.

ARTICLE V.

OTHER MEETINGS OF THE INSTITUTE.

SEC. 1. All meetings of the Institute other than business meetings shall be held at such times and places as the Council may appoint. Notice of all such meetings shall be given to all Members and Associates by mail.

ARTICLE VI.

Directors and Officers.

Sec. 1. The business and financial affairs of the Institute shall be managed by a Board of Directors, who shall be elected at the annual meeting in the manner prescribed in the Certificate of Incorporation.

Sec. 2. The officers of the corporation shall be a President, Vice-President, Secretary and Treasurer, who shall be elected by the Directors from among their number. All such officers shall be elected at the first meeting of the Board of Directors after each annual meeting of the corporation, and shall hold office for one year or until their successors are elected and qualify.

The duties of all officers shall be such as usually pertain to their offices, respectively, together with such other duties as may from time to time be prescribed for them by the By-Laws. The Treasurer shall give a bond for the faithful performance of his duties in a sum to be fixed by the Board of Directors, but at the expense of the Institute.

Sec. 3. In the event of a vacancy occurring in the Board of Directors by death, resignation or otherwise, the remaining members of the Board may, by a majority vote, elect a successor to fill the vacancy, who shall continue in office until the next annual meeting or until his successor shall have been chosen.

Sec. 4. The Board of Directors may, in its discretion, declare the place of any Director vacant, on his failure for any reason, to attend three successive meetings of the Board. Any Director who shall under this section or in any other manner cease to be a member of the Board shall, at the same time, be held to have vacated any other office to which he shall previously have been elected; and the Board shall elect a new incumbent to the said vacant office

Sec. 5. The Board of Directors may from time to time appoint from their own number standing and special committees, and may delegate to such committees such duties as they may see fit.

ARTICLE VII.

Meetings of the Board of Directors.

Sec. 1. A regular meeting of the Board of Directors for the election of officers and the transaction of other business shall be held on the third Tuesday in February in each year, after the adjournment of the annual meeting of the Institute.

Sec. 2. Special meetings of the Board of Directors, at which any business may be transacted, may be called to meet at any time at the office of the Institute in the City of New York, by notice in writing mailed at least five days before the meeting, by the Secretary to each member of the Board at his last known Post-Office address, signed either by the President or the Vice-President or by three members of the Board.

Sec. 3. At all meetings of the Board of Directors the presence of five members shall constitute a quorum.

ARTICLE VIII.

The Council.

Sec. 1. The professional, technical, scientific and social interests of the Institute shall be committed to the supervision of a Council composed of a President

of the Council, six Vice-Presidents of the Council, a Secretary of the Council and nine Councilors, who shall be elected from among the Members and Associates of the Institute in the manner hereinafter prescribed. Members of the Council may or may not be members of the Board of Directors.

SEC. 2. The President of the Council shall be elected for one year, and no person shall be eligible for immediate re-election to this office who shall have held the same for two consecutive years.

After the first year Vice-Presidents of the Council shall be elected to serve for two years, and Councilors shall be elected to serve for three years. No Vice-President of the Council or Councilor shall be eligible for immediate re-election to the same office at the expiration of the term for which he was elected. The Secretary of the Council shall be elected annually.

SEC. 3. At the first annual meeting to be held in the year 1905, there shall be elected a President of the Council to serve for one year, a Secretary of the Council to serve for one year, three Vice-Presidents of the Council to serve for one year, three Vice-Presidents of the Council to serve for two years, three Councilors to serve for one year, three Councilors to serve for two years, and three Councilors to serve for three years. At each subsequent annual meeting there shall be elected a President of the Council to serve for one year; a Secretary of the Council to serve for one year, three Vice-Presidents of the Council to serve for two years; and three Councilors to serve for three years The term of office of all Members of the Council shall continue until the adjournment of the meeting at which their successors are elected.

SEC. 4 Vacancies in the Council may occur by death or resignation; or the Council may, by the vote of a majority of all its members, declare the place of any officer or member of the Council vacant, on his failure for one year, from inability or otherwise, to attend the regular meetings or perform the duties of his office. All vacancies shall be filled by the appointment of the Council, and any person so appointed shall hold office for the remainder of the term for which his predecessor was elected or appointed; *provided* that the said appointment shall not render such person ineligible for election to the Council at the next meeting.

SEC 5. The presence of five members of the Council shall constitute a quorum; but the Council may appoint an Executive Committee, or any business coming within the authority of the Council may be transacted at a regularly-called meeting thereof, at which less than a quorum may be present, subject to the approval of a majority of the Council subsequently given in writing to the Secretary and recorded by him with the minutes.

SEC. 6 The election of the Council shall take place at the regular annual meeting of the Institute. Nominations for members of the Council may be sent in writing to the Secretary accompanied with the names of the proposers at any time not less than thirty days before the annual meeting; and the Secretary shall, not less than two weeks before said meeting, mail to every Member or Associate entitled to vote a list of all nominations for each office so received, together with the names of the persons ineligible for election to each office; and if the Council or a Committee thereof, appointed for the purpose, shall have recommended any nomination, such recommendation may also be sent to the Members and Associates with the list of all nominations made.

ARTICLE IX.

Meetings of the Council.

Sec. 1. Meetings of the Council shall be held at such times and places as the President of the Council or one of the Vice-Presidents of the Council may appoint.

Sec. 2. A meeting of the Council may be held on the day of the annual meeting of the Institute without previous notice. Written notice of all other meetings of the Council, specifying the time and place of such meeting, signed by the Secretary, shall be mailed to every member of the Council at his last known Post-Office address at least ten days before the date of the meeting.

ARTICLE X.

Papers and Publications.

Sec. 1. The Council shall have power to decide as to the acceptance and publication of any professional papers presented to the Institute, subject to such conditions as the Board of Directors may prescribe.

Sec. 2. The copyright of all professional papers communicated to and accepted by the Institute shall be vested in it, unless otherwise expressly agreed between the Council and the author. The Institute shall not assume responsibility for any statements of fact or opinion advanced in the papers or discussions at its meetings. Neither the Council nor the Institute shall officially approve or disapprove any technical or scientific opinion or any proposed enterprise, outside of the management of the meetings, discussions and publications of the Institute, and the conduct of its business affairs by the Board of Directors.

Sec. 3. Special Committees may from time to time be appointed by the Council to make investigations and prepare reports for presentation to the Institute, but no action shall be taken binding the Institute for or against the conclusions embodied in any such reports.

ARTICLE XI.

Suspensions and Expulsions.

Sec. 1. Any member of the Institute who shall be convicted of a crime involving, in the opinion of the Board of Directors, moral turpitude, shall, upon the passage by the Board of Directors of a resolution declaring the crime for which he has been convicted to be of such character, be thereupon dropped from membership in this Institute.

Sec. 2. Any member of the Institute may be suspended or expelled for misconduct by the Board of Directors, after charges setting forth such misconduct shall have been prepared by the Council and filed in writing with the Board. Upon the receipt of such charges in writing, the Board may, in its discretion, suspend such member pending a hearing and determination thereupon As soon as may be after the receipt of such charges, the Board shall fix a date for a hearing thereupon and shall give to the accused member notice thereof in writing, mailed to him at his last known Post-Office address not less than thirty days before said date, accompanied by a full copy of the charges and a copy of the second, third and fourth sections of this article.

Sec. 3. Upon the day fixed for the hearing, the accused member may appear before the Board, either in person or by an accredited representative ; hear any

witnesses who may be called in support of the charges and at his option cross-examine the same ; and hear read any documentary evidence offered in support of the charges. The accused may, in his discretion, produce and examine witnesses in his defence, and submit documentary evidence, including a statement from himself in writing. After the conclusion of the hearing, the Board of Directors shall consider and vote to approve or disapprove the charges. If the Board shall, by a vote of two-thirds of its members, declare the charges sustained, it may suspend the member for a stated period or expel him.

SEC. 4. If the accused member shall not appear at the hearing, and shall within three months thereafter file with the Board an affidavit stating that he had not received notice of the charges against him in time to enable him to present his defence, the Board shall fix a date for a re-hearing within three months from the receipt of such affidavit and shall immediately notify the accused member by mail of such date. Upon the re-hearing, the accused shall have the same privilege of presenting his defence as he would have had upon the original hearing ; and after the defence is presented, the Board shall take a new vote upon the charges, the result of which shall be conclusive.

SEC. 5. All interests in the property of the Institute of persons resigning, or otherwise ceasing to be Members or Associates, shall vest in the Institute.

ARTICLE XII.

AMENDMENTS.

SEC. 1 This Constitution or any Article or Section thereof may be amended at any annual meeting by a two-thirds vote of all the members present in person or by proxy, *provided* that notice of the proposed amendment shall have been given in writing at a previous meeting, and *provided also* that the amendment or amendments so adopted shall have been printed and mailed to all Members and Associates not later than thirty days before the annual meeting. Any amendment or amendments approved by a majority of the votes cast shall be deemed to have been adopted, and shall become a part of this Constitution. The Secretary shall forthwith print and distribute to Members and Associates an announcement of the result of said vote, and if any amendment or amendments shall have been adopted, a copy of the section or sections so amended.

BY-LAWS.

[ADOPTED FEBRUARY 21, 1905. AMENDED FEBRUARY 20, 1906.]

I. PRESIDING OFFICERS.

At all Business meetings of the Institute the President, or, in his absence, the Vice-President, or, in the absence of both of them, any other member of the Board of Directors to be chosen by the meeting, shall preside.

At all other meetings of the Institute the President of the Council or, in his absence, one of the Vice-Presidents, if present, shall preside.

II. ORDER OF BUSINESS.

At each Business meeting of the Institute the order of business shall be as follows:

1. Reading of minutes of preceding meeting.
2. Report of the President.
3. Report of the Treasurer.
4. Report of the Secretary.
5. Election of Directors.
6. Election of Members of the Council.
7. Reports of Standing Committees.
8. Reports of Special Committees.
9. Special Orders.
10. Miscellaneous business.

This order of business may be changed by a vote of a majority of the Members and Associates present in person or by proxy.

The usual parliamentary rules shall govern all meetings of the Institute except in cases otherwise provided by the Constitution or the By-Laws

At all sessions of the Institute other than business meetings, the order of proceedings and the time of adjournment shall rest in the discretion of the presiding officer.

III. SECRETARY.

The Secretary shall keep a record of the proceedings of all meetings of the Institute. He shall be custodian of the Corporate Seal, of the Minute Books, and of all Legal Documents belonging to the Institute. He shall conduct, on behalf of the Institute, all correspondence relating to business matters, except such as pertains directly to the office of the Treasurer

He shall notify all officers and Directors and Members of the Council, and all Members of Committees of their election and appointment; shall issue notices of all meetings of the Board, and of the annual and other meetings of the Institute; and shall, in calling special meetings of the Directors, specify the object of such meeting.

IV. SECRETARY OF THE COUNCIL.

The Secretary of the Council shall act as the Clerk of that body at all of its meetings and at all meetings of the Institute called for the discussion of professional, technical or scientific matters, or for any other purpose than the transaction of business.

He shall be custodian of all technical or scientific papers submitted to the In-

stitute for its consideration, shall have charge of the editing and printing of all material published by the Institute, and of the distribution thereof. On the first day of May following the year in which each volume of *Transactions* is printed, he shall turn over to the Library Committee all copies of the same not theretofore distributed by him. He shall have charge of all the correspondence of the Institute relating to other than business affairs.

The Secretary of the Council shall receive a salary to be fixed by the Board of Directors. He may appoint an Assistant [with the title of] Editor, who shall likewise receive a salary to be fixed by the Board of Directors.

The Secretary of the Council may or may not be the same person as the Secretary of the Institute.

V. Assistant Secretary.

The Secretary may, with the approval of the Board of Directors, appoint an Assistant to whom both he and the Secretary of the Council may delegate such of his or their duties as he or they may see fit. This Assistant Secretary shall receive such salary as shall be fixed by the Board of Directors, which shall cover his services both to the Secretary and to the Secretary of the Council.

VI. Treasurer.

The Treasurer shall collect and, under the direction of the Board of Directors, shall disburse all funds of the Institute. He shall keep regular accounts in books belonging to the Institute, which shall be open to any member of the Board of Directors He shall report in writing at each annual meeting of the Institute and at every meeting of the Board of Directors at which such report shall be called for, the balance of money on hand, and any existing appropriation which may affect the same.

His accounts shall be audited annually by a Committee of three Members or Associates to be appointed by the President at least thirty days prior to the annual meeting in each year, which Committee shall report thereon at such annual meeting.

The Treasurer may, at his discretion, place funds of the Institute, not at any time exceeding $5,000, in a special account in a Bank or Trust Company, subject to the draft of the Assistant Treasurer, and may delegate to the Assistant Treasurer the duty of paying, out of this account, the current expenses of the Institute.

The Treasurer shall be solely responsible to the Institute for all moneys received, whether the same are entrusted to the Assistant Treasurer or not.

VII. Assistant Treasurer.

The Treasurer may appoint, with the approval of the Board of Directors, an Assistant Treasurer, to whom he may delegate the duty of conducting the correspondence incidental to the office of Treasurer, of receiving and depositing in bank to the credit of the Institute all moneys received, and of paying, out of the special account upon which he may be authorized to draw, the necessary expenses of the Institute. The Treasurer may require of him a bond, running to the Treasurer personally, in an amount not exceeding $5,000, the expense of which shall be borne by the Institute.

The Assistant Treasurer shall receive such compensation as shall be fixed by the Board of Directors.

The offices of the Assistant Secretary and of the Assistant Treasurer may, if

so desired by both the Secretary and the Treasurer and approved by the Board of Directors, be united in the same person, who shall then receive the salary of both offices.

The Assistant Treasurer may, with the approval of the Board of Directors, employ such persons as are necessary to constitute a clerical and office force for himself, the Assistant Secretary and the Secretary of the Council, at such salaries as shall be approved by the Board of Directors. He shall, if the offices of Assistant Secretary and Assistant Treasurer be united in the same person, be the immediate superior of all such employees, unless the Secretary of the Council or the Treasurer be present, in which event either of them shall be the superior of all employees, including their respective assistants.

VIII. Standing Committees.

The Standing Committees of the Institute shall be three in number, known respectively as the Finance Committee, the Library Committee and the Committee on Membership.

The Finance Committee and the Library Committee shall each consist of three members of the Board of Directors, and shall be appointed by the President at the first meeting of the Board, after the annual meeting in each year.

The Committee on Membership shall consist of five Members of the Council, and shall be appointed by the President of the Council, at the first meeting of the Council after the first annual meeting in each year.

IX. Finance Committee.

It shall be the duty of the Finance Committee to inquire into and examine the financial condition of the Institute, and to consider ways and means of increasing its revenues and of limiting its expenses. It shall report from time to time to the Board as often as it may deem expedient, and whenever it shall be directed so to do; and the Treasurer shall at all times furnish it with such statements and information as it may desire.

It shall determine the investment of such surplus moneys as shall from time to time accrue to the Institute. It shall, at least once in each year, examine the securities belonging to the Institute in the custody of the Treasurer, and report thereon to the Board.

It may, at any time, examine the books and vouchers of the Treasurer and Assistant Treasurer.

The Treasurer shall not be a member of the Finance Committee, but shall attend the meetings of the same if requested to do so.

X. Library Committee.

The Library Committee shall be the custodian of all books in the Institute Library and of additions thereto; also of all back numbers of the *Transactions* of the Institute. It shall, on the first day of May, of each year, receive from the Secretary of the Council, and receipt for same to him, all the volumes of *Transactions* for the preceding year, not then distributed by said Secretary.

It shall cause to be kept, under the direction of the Assistant Secretary, a catalogue of all books in the Library and an account in ledger form of all volumes of *Transactions* in its custody, in which shall be charged to it all volumes delivered to it, and in which shall be credited all volumes taken from its custody for sale or for any other purpose.

The receipts from the sale of any volume of *Transactions* taken from the custody of the LIBRARY COMMITTEE shall be credited to the LIBRARY COMMITTEE on the books of the Treasurer, and devoted to the general purposes of the Institute.

XI. COMMITTEE ON MEMBERSHIP.

All nominations for Members or Associates of the Institute shall be submitted to and passed upon by the COMMITTEE ON MEMBERSHIP, who shall report thereon to the Council. It shall receive and consider all communications respecting candidates, and shall make diligent inquiry as to the character and qualifications of each one. Its proceedings shall be secret and confidential.

No member of the Committee shall propose any candidate.

XII. ELECTION OF MEMBERS.

After the COMMITTEE ON MEMBERSHIP shall have reported to the Council its conclusions as to the acceptability of each candidate, the Council shall vote upon the same.

Two negative votes of members of the Council present shall prevent the election of any candidate. No person shall be proposed for election to the Institute within one year after his name shall have been rejected by the Council.

XIII UNITED ENGINEERING SOCIETY.

The Board of Directors shall, at its first meeting after the adoption of these By-Laws, designate three Members or Associates of this Institute to be representatives of this Institute upon the Board of Trustees of the UNITED ENGINEERING SOCIETY, making at the same time provision for the expiration of the terms of office of said representatives, as provided in the By-Laws of the said UNITED ENGINEERING SOCIETY.

At the last meeting of the Board of Directors prior to the first day of each January thereafter, the Board shall designate a Member or Associate of this Institute to be a representative of this Institute upon the Board of Trustees of the said UNITED ENGINEERING SOCIETY for a period of three years beginning at the next ensuing annual meeting of said Society

At any time when a vacancy shall occur in the representation of this Institute in the Board of Trustees of said Society, by reason of the death, resignation or removal of any such representative therein, the Board of Directors of this Institute shall designate a Member or Associate to fill such unexpired term.

XIV. AMENDMENTS.

These By-Laws may at any time be altered or amended by a vote of three-fourths of the Board of Directors, or by the Members, at a business meeting of the Institute, in the same manner provided for amendments of the Constitution in Article XII. thereof.

In By-Law IV., p. xxv, the words included in brackets were introduced by an amendment adopted at the Second Annual Meeting, February 20, 1906.

The election of officers by vote of the members and associates present in person or by proxy at the Annual Meeting, February 21, 1905, resulted as follows:

COUNCIL.

President of Council.

James Gayley,	New York, N. Y.

Vice-Presidents of Council.

(To serve one year)

George W. Maynard,	New York, N Y
Julian Kennedy,	Pittsburg, Pa.
Charles D. Walcott,	Washington, D. C.

(To serve two years)

William P. Blake,	Tucson, Ariz
Thomas F Cole,	Duluth, Minn
Irving A. Stearns,	Wilkes-Barre, Pa.

Secretary of Council

R. W. Raymond,	New York, N Y.

(To serve one year)

Councilors.

(To serve one year.)

Frank Klepetko,	New York, N. Y.
Benjamin B Lawrence,	New York, N. Y.
Heinrich Ries,	Ithaca, N. Y.

(To serve two years)

F. L. Grammer,	Baltimore, Md.
Joseph Hartshorne,	Pottstown, Pa
Charles H. Snow,	New York, N. Y.

(To serve three years)

A. A Blow,	Denver, Colo.
Frank Lyman,	New York, N. Y.
T A. Rickard,	New York, N. Y.

DIRECTORS OF THE CORPORATION.

For one year, T. A. Rickard, Charles H. Snow and R. W. Raymond;
For two years, James Gayley, Frank Klepetko and Frank Lyman;
For three years, James Douglas, James F. Kemp and Albert R. Ledoux.

At a meeting of the Board of Directors, held February 21, 1905, after the adjournment of the annual meeting, the following officers were elected: *President*, James Gayley; *Secretary*, R. W. Raymond; *Treasurer*, Frank Lyman.

FINANCIAL REPORT.

At the Annual Meeting of the Corporation, February 21, 1905, the Secretary was instructed to publish, for the information of members, a statement of the receipts and expenditures of the unincorporated American Institute of Mining Engineers, for the year 1904, and to the 9th day of January, 1905, the date of the incorporation of this Institute.

In pursuance of the above instructions, the Secretary publishes the statement of receipts and payments for the above period, duly certified by Barrow, Wade, Guthrie & Company, certified public accountants.

RECEIPTS.

1904.		
Jan. 1.	To Balance forward from last year,	$6,625 65
1905.		
Jan 9	To Dues, etc:	
	Annual Dues,	38,087 37
	Life Memberships,	1,250 00
	Initiation Fees,	1,030 30
	To Binding of *Transactions*,	3,650 33
	Sale of Publications,	3,546 87
	Electrotypes,	166 30
	Miscellaneous,	387 88
	To Interest received:	
	Pennsylvania Railroad $13,000 General Mortgage Bonds at 6 per cent.,	780 00
	United States Government $2,900 4 per cent. Bonds,	29 00
	New York Central & Hudson River R. R Lake Shore Collateral $6,000 3½ per cent Bonds,	210 00
	Bank Deposits,	261 72
	To Reimbursement from Library Fund for Purchase of Books,	2,051 56
	To Sale of Bonds:	
	United States Government $2,900 4 per cent. Bonds,	3,129 28
		$61,206 26
1905.		
Jan. 9.	To Balance represented by Cash in Banks and on hand,	$9,401 58

PAYMENTS.

1905.			
Jan. 9.	By Expenditures for the year:		
	Printing Volume xxxiii. of the *Transactions*,	$1,729 15	
	Printing Volume xxxiv of the *Transactions*,	4,070 19	
	Printing Pamphlet Edition of Papers,	6,686 21	
	Printing Circulars and Ballots,	512 75	
	Binding Volume xxxiii. of the *Transactions*,	2,485 00	
	Binding Volume xxxiv. of the *Transactions*,	2,735 37	
	Binding Miscellaneous Volumes,	427 95	
	Binding of Exchanges,	191 40	
	Engraving and Electrotyping,	1,211 53	
	By Editorial Appropriation and Salaries:		
	Secretary's department, including Clerks, Stenographers and expenses of proofreading and editing,	8,839 26	
	Assistant Secretary's and Assistant Treasurer's department,	6,757 73	
	Librarian and Assistant,	1,281 00	
	Postage, including Post Office Box rental,	3,741 96	
	Stationery,	733 23	
	Rent,	2,708 33	
	Express and Freight Charges,	3,147 87	
	Telephone,	289 39	
	Telegrams, Cables and Carfare,	85 24	
	Storage of *Transactions*,	154 20	
	Office Supplies and Repairs,	325 89	
	Refunding Payments,	16 26	
	Insurance Premiums, Fire and Surety,	207 75	
	Collection Charges,	24 78	
	Extra Clerical help,	239 65	
	Special Stenographers and expenses of Meetings,	1,122 28	
	Auditing,	75 00	
	Incorporation Expenses,	2 00	
			$49,801 37
	By Office Equipment,	333 52	
	Library Additions,	1,669 79	
			2,003 31
	By Balance,		9,401 58
			$61,206 26

New York, N. Y., February 17, 1905.

We have examined the above statement, compared it with the books and vouchers and find same correct In addition to the balance of Cash in Banks and on hand of $9,401.58, the Institute own Investments of a par value of $19,000, consisting of thirteen (13) Registered 6 per cent. Bonds of The Pennsylvania Railroad Company, $13,000, and six (6) 3½ per cent. Bonds of the New York Central and Hudson River Railroad Co. Lake Shore Collateral, $6,000 These Securities have been examined by us and found to be in order.

(Signed) Barrow, Wade, Guthrie & Co.,
Certified Public Accountants.

REPORT OF THE COUNCIL FOR THE YEAR 1904.

During the year, two Meetings of the Institute were held, the Eighty-sixth, in February, at Atlantic City, N. J., and the Eighty-seventh, in September, in the Lake Superior region, with a supplementary session at St. Louis, Mo. The proceedings of both these meetings, and accounts of the excursions connected therewith, which will be published in Vol. XXXV. of the *Transactions*, bear witness to their delightful and instructive character, as well as to the great value of the papers and discussions.

At the close of the year, the publication of the *Bi-Monthly Bulletin* was decided upon, to begin in January, 1905.

Changes in membership have taken place during the year as follows: 276 members and 29 associates have been elected; 19 associates have become members; 3 members have been reinstated in payment of arrears of dues, coupled with satisfactory explanation of previous default; 2 honorary members, 37 members and 2 associates have died; 39 members and 8 associates have resigned; and 45 members have been dropped for non-payment of dues. These changes are tabulated as follows:

Membership of the American Institute of Mining Engineers, January 1, 1905.

	H. M.	M.	A.	Totals.
Membership Dec. 31, 1903	9	3,306	190	3,505
Gains: By Election	....	276	29	305
Change of Status	....	19	....	19
Reinstatement	....	3	....	3
Losses: By Resignation	....	39	8	47
Dropping	....	45	....	45
Change of Status	....	....	19	19
Death	2	37	2	41
Total gains	....	298	29	327
Total losses	2	121	29	152
Membership Dec. 31, 1904	7	3,483	190	3,680

The list of deaths reported during the year 1904 comprises the following names (the figures in parenthesis indicate the year in which the persons named were elected to membership).

Members Deceased, 1904.

Honorary Members.—Sir Lowthian Bell (1897), Dr. Thomas Messenger Drown (1871: Honorary, 1883).

Members and Associates.—Jacob Neff Barr (1884), A. P. Blandy (1903), A. Cass Canfield (1876), William E. Carroll (1901), *William E. C. Coxe (1874), Russell W. Davenport (1877), *Isidor Davidov (1893), †Louis Davidson (1889), Louis M. Davis (1884), †Frederick W. Dobler (1902), Edward Doerr (1897), Louis C. DuBois (1900), Edward M. Ferguson (1878), C. Le Neve Foster (1893), George Clinton Gardner (1878), William J. Harris (1871), H. D. Hoskold (1894), William S. Hungerford (1882), Edward P. Landis (1882), August Lengemann (1902), William M. Lippitt (1900), Robert J. McCartney (1897), Henry McCalley (1888), A. McClellan (1871), Arthur S. Mahony (1888), Philip W. Moen (1888), H. G. Morse (1881), Clarence V. Page (1900), Charles Parkin (1875), Rubens P. Patterson (1886), Henry Paul (1889), William H. Pettee (1871), James B. Randol (1879), Irving W. Sevier (1904), William J. Sims (1902), John H. Slavens (1901), *Charles B. Squier (1886), Charles W. Stickney (1891), Homer H. Swaney (1903), Oliver Williams (1887), Walter B. Wilson (1892), Whittaker Wright (1881).

Of these, Sir Lowthian Bell, Dr. Thomas Messenger Drown, Sir Clement Le Neve Foster, and Prof. William H. Pettee have been the subjects of special Biographical Notices.

[Secretary's Note.—Obituary paragraphs concerning other names in this list were published in the *Bi-Monthly Bulletin*, No. 4, July, 1905, p. 761.—R. W. R.]

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* Death not reported until after January 1, 1905, and, therefore, not included in the table on p. xvi

† Death occurred in 1903, but not reported until after January 1, 1904, and therefore included in the table on p. xxix.

Membership.

The following list comprises those persons elected as members who duly accepted election during the months specified:—

November and December, 1904.

Members.

Philippe D. Ahier,	Seaforth, Liverpool, England.
James E. Chapman,	Guayaquil, Ecuador, S. A.
W. S McChesney, Jr.,	St. Louis, Mo.
Arthur H. Collbran,	Seoul, Korea.
Herbert W. Fane,	Mertola, Portugal.
Herbert L. Holt,	Edgemont, Nev.
Walter L. Johnson,	Port Clarence, Middlesbro, England.
Robert R. Jones,	Chicago, Ill.
Andrew B. Rawn,	Dott, W. Va.
Gaston Strap,	Paris, France.
Archibald A. Swan,	Altamont, Blair-Gowrie, Scotland
Charles S. Thomas,	Ouray, Colo.
Samuel Whitworth,	London, England.

January and February, 1905.

Members.

Cuyler Adams,	Duluth, Minn.
Edgar C. Agabeg,	Bengal, India
Rupert C. Alabaster,	Bayswater, London, England.
Peter T. Austen,	New York, N. Y
Melbourne Bailey,	Stanley, B. C , Canada
Karl Baumgarten,	Magdalena, Sonora, Mexico.
Joseph W. Bible,	Hanover, N. M.
Robert Montgomery Bird,	South Bethlehem, Pa.
Edward N Breitung,	Marquette, Mich.
Wallace B. Bretherton,	Val Verde, Ariz.
Raymond Brooks,	Chimney Rock, Park Co , Mont.
Harry H. Burhaus,	San Fernando, Durango, Mexico.
Arthur Howe Carpenter,	Denver, Colo.
David Cole,	Cananea, Sonora, Mexico.
John P. Collins,	Pittsburg, Pa.
Walter H. Crawford,	Nashville, Tenn.
Charles T. Fairbairn,	Virginia, Minn.
Oscar Falkman,	Donora, Pa.
Walter Fitch,	Salt Lake City, Utah.
T. F. M. Fitzgerald,	Flat River, Mo.
Alfred Fox, Jr.,	Avequipa, Peru.
John A. Garcia,	St Louis, Mo.
Alexander S. Garfield,	New York, N. Y.
H W. C. Gender,	Okanagan Landing, B. C., Canada.
Lewis H. Greene,	Los Angeles, Cal.

Charles H. Halcomb,	Syracuse, N. Y.
William J Hamilton,	Aguascalientes, Mexico.
Joseph H. Hutchinson,	Boise, Idaho.
James Duane Ireland,	Camp Bird, Ouray Co., Colo.
Fred L. Johnston,	Berkeley, Cal.
Owen Jones,	Arequipa, Peru.
Fred A. Jordan,	Houghton, Mich.
Carl E. Julihn,	St. Louis, Mo
Harry L. Kaufman,	Marquette, Mich
Charles Kirchen,	Sumpter, Oregon
Ralph Crane Kline,	Lajolla, San Diego Co , Cal.
Watkin W. Kneath,	Salt Lake City, Utah.
Maurice Lindeman,	De Lamar, Nev.
J. M. McClave,	Denver, Colo.
John McGee,	Kendall, Mont.
Mark G Magnuson,	Sonora, Mexico.
F. A. G. Maxwell,	Randfontein, Transvaal, S. A.
Lucius W. Mayer,	Victor, Colo.
Harry T. Mercer,	Trimountain, Mich.
Thomas H. O'Brien,	Fierro, N. M.
Edwin N. Ohl,	Pittsburg, Pa
Robert S Oliver,	Trimountain, Mich.
Lewis E. Paddock,	Duluth, Minn.
Joseph E. Parker,	Bulawayo, Rhodesia, S A.
Talbot E. Pierce,	Syracuse, N. Y.
Harold Playter,	Goldboro, N. S., Canada.
Davis Richardson,	Los Angeles, Cal.
H. F. A. Riebling,	Cripple Creek, Colo.
John J. Rutledge,	Baltimore, Md.
William J. Seaton,	Rosebank, Staten Island, N. Y.
Carlos Sellerier,	Mexico City, Mexico.
Howard I. Shaw,	Kendall, Mont.
Thomas Henry Sheldon,	Victor, Colo.
Charles Harold Showers,	Colima, State of Colima, Mexico.
Tomas Solomon,	Pachuca, Mexico.
Harry Stansfield,	Auckland, New Zealand
Charles C. Starr,	Wardner, Idaho.
John W. Stull,	Lignite, Va.
Kuchiro Takagi,	Chikugo, Japan.
Edward T. Temby,	Francistown, Matabeleland, S A.
Edward T. Thornton,	Velardena, Durango, Mexico.
Bruce Walter,	Pittsburg, Pa
George Wilcox,	Franklin Furnace, Sussex Co , N. J.
Edwin C. Witherby,	Syracuse, N. Y.
Samuel S. Wyer,	Columbus, Ohio.

ASSOCIATES.

Lawrence M. Buck,	Baltimore, Md.
Thomas Truman Fulton,	Bass River, N. S., Canada
Ambrose E. Ring,	New York, N. Y.
Benjamin F. Tillson,	New Haven, Conn.

March, 1905.

Members.

John C. Barber	Prince of Wales Island, Alaska.
John F. Bouchelle	New York, N. Y.
William W. Bowron	Chattanooga, Tenn.
James L. Boyle	Los Angeles, Cal.
Thomas Breakell	Brassington, England.
Henry C. Carr	San Francisco, Cal.
James W. Chenhall, Jr	Totnes, England.
George R. Comings	Greaterville, Ariz.
R. A. Crespi	Costa Rica, Central America.
James C. Draper	Rolla, Mo.
John W. Duffus	Durango, Mexico.
George F. Dunkle	Philipsburg, Pa.
Arthur B. Foote	Grass Valley, Cal.
Charles D. Fuller	Latrobe, Pa.
George H. Garrey	Washington, D. C.
Thomas S. Gore	Victoria, B C.
Independence Grove	Youngstown, O.
Franklin Guiteman	Denver, Colo.
Albert S. Halley	Rapid City, S. Dak.
George K. Hamfeldt	Rankin, Pa.
S. Harbert Hamilton	Trenton, N. J.
Christian Hanckel	Liverpool, England.
Richard S. Haseltine	Berkeley, Cal.
Ledyard Hecksher	Philadelphia, Pa.
Thomas F. Hildreth	Niagara Falls, N. Y.
John W. Ingersol	Deadwood, S. Dak.
Maurice M. Johnson	Salt Lake City, Utah.
Henry S. Kimball	Flat River, Mo.
Henry Krumb	Los Angeles, Cal.
A. F. Kuehn	Sumpter, Ore.
Alarik Larson	Striberg, Sweden.
Arthur H. Lawry	Goldfield, Nev.
Engbert A. Lee	Denver, Colo.
Neville Leese	Ocampo, Mexico
Roscoe R. Leslie	Sonora, Mexico.
Thomas S. Lippy	Seattle, Wash.
Robert R Maffett	Bayonne, N. J.
Frank C. Mandell	Hailey, Idaho.
Richard Marsh	Rossland, B. C.
George L. Miller	Bitumen, Pa.
George F. Moser	Manse, Nev.
John C. Osgood	Redstone, Colo.
Charles H. Page	Butte, Mont.
Julius L. Partz	Carters, Cal.
George D. Reid	Mineral, Idaho.
Joshua W. Rhodes	Pittsburg, Pa.
Joseph W. Richards	Bethlehem, Pa.
Oscar Rohn	Madison, Wis.

Lloyd A. Rone,	San Luis Potosi, Mexico.
Gilbert McM. Ross,	Copperopolis, Cal.
Clarence C Rothschild,	Flat River, Mo.
John D. Ryan,	Butte, Mont.
Robert H. Stewart,	Rossland, B. C.
William L. Study,	Bigbend, Texas.
Clarence B. Sturges,	Scranton, Pa.
Edward J. Taylor,	Pittsburg, Pa.
Richard H. Vail,	West Jordan, Utah.
Benjamin W. Vallat,	Virginia, Minn..
Eugene E. Whiteley,	Bisbee, Ariz.
Robert Y Williams,	Upper Potomac, W Va.

Associates.

William P. Harlow,	Boulder, Colo.
George G. Higbee,	Burlington, Iowa.
Theodore H. Lasley,	Chattanooga, Tenn
Samuel Newhouse,	Salt Lake City, Utah.

From May 1 *to June* 15, 1905.

Members.

John B Aarons,	Kalgoorlie, Western Australia.
Masayoshi Abe,	Kyoto, Japan
Pedro T Aguilera,	Santiago de Cuba, Cuba
Albert M. Austin,	Llano, Sonora, Mexico
Alfred L. Bloomfield,	Uralla, N. S. W., Australia.
William A. Bostwick,	Pittsburg, Pa.
James Breen,	Spokane, Wash
Joseph W Brill,	Oaxaca, Mexico.
Edward E Bugbee,	Ames, Iowa.
William A Caldwell,	Minas Geraes, Brazil, S. A.
Lawrence B Carpenter,	Basin, Ariz
John B Dilworth,	Philadelphia, Pa.
Harold Hope-Doeg,	Torres, Sonora, Mexico.
Edwin S. Dougherty,	Tirapata, Peru, S. A.
Newton C. Fassett,	Tonopah, Nev.
Frank Fitch,	Magdelena, Sonora, Mexico.
J. M. Aldape-Garza,	Torreon, Coahuila, Mexico.
Robert H. Geoghegan,	Provincia de Huelva, Spain.
Ernest Gordon,	Guadalajara, Mexico.
William W. Graham,	Mexico City, Mexico.
George A. Guess,	Silverton, Colo
Oscar Halvorsen,	Two Harbors, Minn.
William L Hammer,	Welch, W. Va.
Armin Harms,	Ingot, Cal.
Henry Harris,	Nelson, B. C., Canada.
Robert R. Hedley,	Nelson, B. C , Canada.
Fritz Heise,	Bochum, Germany.
Erskine Hewitt,	New York, N. Y.
Edmund O. Hovey,	New York, N. Y.

Claude E. Jamison,	Mojave, Cal.
Albert W. Johnston,	New York, N Y.
I. Wayne von Leer,	El Carmen, Durango, Mexico.
Herbert H. Light,	Hermosillo, Sonora, Mexico.
E. C. Luther,	Pottsville, Pa
Edward McGrew,	Pittsburg, Pa.
Joseph F Menzies,	Roslyn, Wash.
Mansfield Merriman,	Bethlehem, Pa.
Reginald B. Mildon,	Denver, Colo.
Jesse W. Miller,	San Nicolas del Oro, Guerrero, Mexico.
John D. Millen,	Launceston, Tasmania.
Warner Moore,	Richmond, Va.
Robert H Morris,	Gloucester, Ohio.
Cleveland O. Moss,	Silverbell, Ariz.
Augustus Munson,	Hibernia, N. J.
Clive S. Newcomb,	Ouretaro, Mexico.
Wheeler O. North,	Mojave, Cal.
William G. Page,	Hailey, Idaho.
William R. Pearson,	Norwalk, Ohio.
Gustaf W Petersson,	Stockholm, Sweden.
René Proust,	Perak, Federated Malay States.
Frank D. Rash,	Earlington, Ky.
Pietro Redaelli,	Lecco, Lombardy, Italy
Clarence E Rhodes,	Mexico City, Mexico
Arthur J. Rickard,	Minas Geraes, Brazil, S A
Jacob H. Robeson,	Denver, Colo.
Armine G. Rusden,	Johannesburg, Transvaal, So Africa.
Albert W. Sayles,	New York, N. Y.
Fred J. Shaler,	Pittsburg, Pa.
Franklin P. Sherwood,	New York, N. Y.
Samuel A Taylor,	Pittsburg, Pa
Marion Lee Thomas,	Bonanza, Zacatecas, Mexico.
Rees C. Vidler,	Georgetown, Colo.
Hobart S. Vincent,	Deadwood, S. D.
Harry L. Waste,	Mt. Bullion, Cal
Berndt E. Wijkander,	Bofors, Sweden
Burton L. Wolfe,	Cananea, Sonora, Mexico.
Herbert B. Wright,	Fernie, B. C., Canada
William E. Zwicky,	Kaslo, B. C., Canada.

Associates.

Charles R. Hart,	Guanacevi, Durango, Mexico.
Charles D. Marvin,	New York, N. Y.
Victor M. Tyler,	New Haven, Conn.
James S. Wyatt,	Bourne, Oregon.

From June 15 *to September* 1, 1905.

Members.

Darsie C. Bard,	Butte, Mont.
Stanislaus C. N. Bell,	Derby, Tasmania.

Robert C. Botsford,	London, England.
Harry S. Denny	Johannesburg, South Africa.
George E. Farish,	Torres, Sonora, Mexico.
James Fergusson,	Gawler, South Australia.
James Findlay,	Vancouver, B. C., Canada.
Minett E. Frames,	Johannesburg, South Africa.
Ambrose W. Freeman,	Sydney, N. S. W., Australia
William A. Freymuth,	Mandalay, Burma, India.
Edward C. Gage,	San Deimas, Durango, Mexico.
Robert W. Gordon,	Rhyolite, Nev.
Louis A. Greenley,	Portland, Ore.
Ludwig Hundeshagen,	Stuttgart, Germany.
Tsunema Kuroda,	Chikugo, Japan.
Clermont Livingston,	Vancouver, B. C., Canada.
J. Edgar McAllister,	Greenwood, B. C., Canada.
Mark M. Marks,	Zeehan, Tasmania.
Hugh F. Marriott,	Johannesburg, South Africa.
James G. Mason,	Johannesburg, South Africa.
Jaguanharo de Miranda,	Rio de Janeiro, Brazil, S. A.
George H. Playter,	Joplin, Mo.
Joseph R. Raleigh,	Stannery Hills, Queensland, Australia
Peter A. Raymond,	Tezuitlan, Pueblo, Mexico.
Harry De C. Richards,	San Francisco, Cal.
Leopoldo Rivera,	Ixtlan, Oaxaca, Mexico
F. G. Scheffler,	Rio Grande Do Sul, Brazil, S. A.
August Schwemann,	Aachen, Germany.
Herbert R. Sleeman,	London, England.
Richard L. Smith,	Pittsburg, Pa.
Henry St. J. Somerset, Jr.,	Mount Morgan, Q. Australia.
Henry Steel,	Rotherham, England
Thomas E. Steele,	La Cananea, Sonora, Mexico
Alfred Tellam,	La Cananea. Sonora, Mexico.
James A. Thomas,	San Francisco, Cal
Ewen D. H Thomson,	Gopeng, Perak, Fed. Malay States.
Herbert E. Vail,	Mount Sir Samuel, West Australia.
Gedeon A. Voskule,	Johannesburg, South Africa.
John E. Warn,	Neroigunoah, N. S. W., Australia.
Herman Wendler,	San Francisco, Cal.
John A. B. Wesley,	Gawler, South Australia.
James R. Whipple,	Juneau, Alaska.
C W. Whitley,	Salt Lake City, Utah.
Ralph B. Williams,	Guayaquil, Ecuador, S. America.
Charles W. Wright,	Washington, D C.
Fritz Wust,	Aachen, Germany.

Associate.

John B. Du Faur,	Mount Morgan, Q., Australia.

From September 1 *to November* 1, 1905.

Members.

Leo F. Arnold,	Chicago, Ill.
Leon H. Brady,	Asientos, Aguascalientes, Mexico.
Robert W. Brigstocke,	Haileyburg, Ontario, Canada.
Edward E. Brownell,	San Francisco, Cal.
Joseph G. Butler, Jr,	Youngstown, O.
Parker H. Cunningham,	Denver, Colo.
Norris E. Eads,	Victor, Colo.
Louis K. Fletcher,	La Paz, Lower California, Mexico.
William F Fremersdorf,	San Diego, Cal.
Harry A. Gallway,	Butte, Mont.
Esteban Garcia,	Parral, Chihuahua, Mexico.
Harold C. George,	Allegheny, Pa.
Arthur H. Gracey,	Nelson, B C, Canada.
Harry H. Hindshaw,	Albany, N. Y.
James Jack,	Goldfield, Nev.
Walter H. Jackson,	Flat River, Mo.
Neil Kennedy,	London, England.
Merton S. Kingston,	Hibbing, Minn.
Will P. Lass,	Susanville, Ore
Marcellus P. Lee,	Johannesburg, Transvaal, S. Africa.
Hiram D. McCaskey,	Manila, P. I.
Samuel McEwen,	Denver, Colo.
Daniel B. Meacham,	Cincinnati, O
Frederick H. Newell,	Washington, D. C.
Clarence C Playter,	Joplin, Mo
John Polkinghorne,	Cobar, N. S W., Australia.
Carl M. E. Preusse,	Sultepec, Estado de Mexico, Mexico.
Victor Rakowsky,	North Freedom, Wis.
Antonio Olyntho des Santos Pires,	Minas Geraes, Brazil, S. A.
Albert J. Simons	West Borneo, Dutch East Indies.
Frank N. Speller,	Pittsburg, Pa.
Emilio H. Stahlknecht,	Jiminez, Chihuahua, Mexico.
Blamey Stevens,	Ellamar, Alaska.
William F. Strasser,	Hazel Green, Wis.
L J. Tefft,	Butte, Mont.
Chung Yu Wang,	New York, N. Y.
George R. Wood,	Pittsburg, Pa.
J. Edmund Woodman,	Halifax, N S, Canada.
Frederick E. Young,	Vancouver, B. C., Canada.

Life Associate.

Jean Antony Varicle,	Dawson, Y. T., Canada.

Associates.

Melvin H. Harrington,	Philadelphia, Pa.
Ellsworth M. Shipp,	Newburgh, N. Y.

From November 1, 1905, *to January* 1, 1906.

Honorary Member.

Prof Henri Louis Le Chatelier, ... Paris, France.

Life Member.

William C Boschen, ... New York, N. Y.

Members.

R. Scott Allen,	Philadelphia, Pa.
James W. Brown,	Pittsburg, Pa.
Charles E. Corson,	Latrobe, Pa.
Eugene Charles Grice,	Pearl, Idaho.
Robert Hawxhurst, Jr.,	Wei Hai Wei, China.
John L Henry,	San Andreas, Cal.
Frank Albert Hill,	Renton, Wash.
James Horsburgh,	Chillagoe, Queensland, Australia.
Harvey Marion La Follette,	La Follette, Tenn.
James Gourlay Lang,	Baker City, Oregon.
Joaquim de Almeida Lustosa,	Lafayette, Minas Geraes, Brazil, S. A.
Willard Vaughan Morse,	Chihuahua, Mexico.
Albert John Netter,	Vryheid, Natal, So. Africa.
David H. Newland,	Albany, N. Y.
Edward O'Toole,	Gary, West Va.
Henry Harger Scovil,	Latrobe, Pa.
Arthur L. Sweetser,	Chihuahua, Mexico.
Mark Willis Wanless,	Sonora, Mexico.
Theodore Ladd Welles,	Wilkes-Barre, Pa.
Hubert Edwin Whitfield,	Kalgoorlie, Western Australia.
Thomas Anthony Wood,	Duncans, B. C., Canada.

Associates.

Frederic Gamble Bingham Allan,	Deseronto, Ontario, Canada.
Cornelius Francis Kelley,	Butte, Mont.
Frederick W Lyman,	Minneapolis, Minn.
George R. Lyman,	Minneapolis, Minn.
Charles Francis Roe,	New York, N. Y.
Adolphus James Taylor,	Sydney, N. S. W., Australia.

Deaths.

The following list comprises the names of members whose deaths have been reported to the Secretary of the Institute during the year 1905—:

Date of Election	Name	Date of Decease
1903.	*Adams, Charles C,	August 31, 1905.
1898.	**Anderson, John Wesley,	May 19, 1905.
1901.	†Barber, William B,	May 4, 1905.
1900	*Bennett, T. A,	November 22, 1905.
1889	*Best, John W,	August 20, 1904.
1901.	*Bryan, Luke W.,	March 26, 1905.
1874.	*Cooper, Edward,	February 25, 1905.
1905.	*Daugherty, Edwin S,	September ——, 1905.
1875.	*De Camp, W. S,	April 8, 1905.
1889.	*Eldridge, George H.,	June 29, 1905.
1871.	*Frazier, B W.,	January 4, 1905.
1897.	*Guinn, John B.,	May 5, 1905.
1900	*Irish, Dana C.,	Aprll 4, 1905.
Hon.	*Kerl, Dr Bruno,	March 25, 1905.
1899.	†Lee, Harry H,	April 21, 1905
1902.	*Lindsay, William A.,	January 26, 1905.
1884.	*Luther, R. C,	March 6, 1905.
1899.	*McLean, Gordon,	June 6, 1905.
1902.	*McNamara, Herbert H,	January 8, 1905.
1893.	*MacNaughton, James,	December 29, 1905.
1886.	*Meyer, A R,	December 1, 1905.
1897.	*Orr, William,	November 21, 1905.
1898.	*Parker, W. J., Jr.,	July 21, 1905.
1895.	*Philips, Joseph, Jr,	October 13, 1905.
1902.	†Ripley, Charles O.,	September 21, 1905.
1883.	*Schmitz, E J.,	April 5, 1905.
1900.	†Seeger, Ludwig,	March 10, 1905
1900.	*Sperry, Jacob J.,	December 26, 1902.
1902.	*Stoiber, Gustavus H.,	August 1, 1905.
1905.	*Study, William L,	Jnne 8, 1905.
1900.	*Swan, R. M. W,	January —, 1905.
1886.	*Terhune, R. H.,	January 15, 1905
1892.	*Thiry, Joseph,	September 8, 1905
1903.	*Tisdale, John N.,	November 6, 1905.
1897	*Totten, Alfred I,	July 28, 1905.
1902.	*Virgoe, Walter H,	May 18, 1905.
1890.	*Wellman, Charles H.,	June 22, 1905.
1903.	*Williams, Harvey L,	August 4, 1905.

* Member. † Associate. ** Life Member. †† Life Associate.

Proceedings of the Eighty-Eighth Meeting,* Washington, D. C., May, 1905.

Honorary Committee.

Hon. C. D Walcott (*Chairman*), *Director U S. Geological Survey.*
Hon. Frederick I. Allen, *Commissioner of Patents.*
Dr. Frank Baker, *Superintendent National Zoological Park*
Mr. Charles A. Bell, *President American Security and Trust Co.*
Major John Biddle, *Engineer Commissioner of District of Columbia.*
Admiral C. M Chester, *Superintendent U. S. Naval Observatory.*
General William Crozier, *Chief of Ordnance, U. S. A.*
Admiral George Dewey, *Admiral of the Navy.*
Colonel Clarence R. Edwards, *Chief Bureau of Insular Affairs.*
Mr. William C. Fox, *Director Bureau of American Republics.*
Mr. Charles C Glover, *President The Riggs National Bank.*
General A. W. Greely, *Chief Signal Officer, U. S. A.*
Mr. Bernard R Green, *Superintendent Library Building.*
Gen G. H. Harries, *Vice-President Washington Electric Railway Co.*
Hon. E A. Hitchcock, *Secretary of the Interior.*
Commander H. M. Hodges, *Chief Hydrographer, U. S. N.*
Prof. W. H. Holmes, *Chief Bureau of American Ethnology.*
Prof. S. P. Langley, *Secretary Smithsonian Institution.*
General Alexander Mackenzie, *Chief of Engineers, U. S A.*
Admiral N. E. Mason, *Chief Bureau of Ordnance, U. S. N.*
Hon. Wm M. Meredith, *Director Bureau of Engraving and Printing.*
Hon. V. H. Metcalf, *Secretary Department of Commerce and Labor.*
Hon. Willis L. Moore, *Chief U. S. Weather Bureau.*
Hon. Paul Morton, *Secretary of the Navy.*
Mr. F. H. Newell, *Chief Reclamation Service, U. S. Geological Survey.*
Hon. S N D. North, *Director Census Office.*
Capt. E. C. Pendleton, *Superintendent Naval Gun Factory.*
Mr. Gifford Pinchot, *Chief Forester, Department of Agriculture.*
Mr. Herbert Putnam, *Librarian of Congress.*
Admiral Chas. W. Rae, *Chief Bureau of Steam Engineering, U. S. N.*
Mr. Richard Rathbun, *Assistant Secretary Smithsonian Institution.*
Hon. W. T. Richards, *Commissioner General Land Office.*

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* Since the incorporation of the Institute in January, 1905, the annual business meeting is required to be held at New York City, and is entirely distinct from the meetings for the reading of papers, etc., the times and places of which are determined, as heretofore, by the Council. Consequently, the Washington meeting is here regarded (and, in the following volumes of *Transactions*, will be regarded) as a separate meeting, and not as an adjourned session of the annual business meeting held February 21, 1905, in New York City.

The proceedings of the said annual meeting have been already published in the *Bi-Monthly Bulletin* No. 3, March, 1905.

HON. GEORGE E. ROBERTS, *Director of the Mint.*
HON. W. H. TAFT, *Secretary of War.*
HON. O. H. TITTMAN, *Superintendent Coast and Geodetic Survey.*
MR. B. H WARNER, *Trustee Public Library.*
MR. GEORGE WESTINGHOUSE, *President of Westinghouse Air Brake Co.*
MR. MILTON WHITNEY, *Chief Bureau of Soils, Dept. of Agriculture.*
DR. HARVEY W. WILEY, *Chief Chemist, Department of Agriculture.*
HON. JAMES WILSON, *Secretary of Agriculture.*

GENERAL COMMITTEE.

S. F EMMONS (*Chairman*),
J. M. BOUTWELL (*Secretary*),

CLEVELAND ABBE, JR.,
G. H ASHLEY,
H. F. BAIN,
G. F. BECKER,
A. A. BLOW,
G. L. BRADLEY,
A. H. BROOKS,
M. R. CAMPBELL,
R H. CHAPMAN,
T. M CHATARD,
W A CLARK,
N. H. DARTON,
D. T. DAY,
F P. DEWEY,
G. H. ELDRIDGE,
G. K. GILBERT,
W. T. GRISWOLD,
A. HAGUE,
E. B HARDEN,
C. W HAYES,
C. E HESSE,
R. T. HILL,
HENNEN JENNINGS,
W. LINDGREN,
A. F. LUCAS,
G. P MERRILL,
S C MILLER,
C. E. MONROE,
A. F. NATHAN,
E. W. PARKER,
H. C. PERKINS,
GIFFORD PINCHOT,
F. L. RANSOME,
W. B. RIDGELY,
F. C. SCHRADER,
G. O SMITH,
Z T. SOWERS,
A. C. SPENCER,
J. E. SPURR,
GEORGE STEIGER,
H. N. STOKES,
C. D WALCOTT,
T. F WALSH,
W. H. WEED,
G. F. WILLIAMS,
F. E. WRIGHT.

The opening session was held Tuesday evening, May 2, 1905, in the Banquet Hall of the Hotel Arlington. President James Gayley called the meeting to order. Mr. Macfarland, Commissioner for the District of Columbia, welcomed the members of the Institute and their guests in a cordial address, to which Mr. Gayley responded.

Mr. Charles Kirchhoff outlined the progress made in connection with the Carnegie Building for the three national engineering societies.

Dr. R. W. Raymond gave a brief review of the work attending the recent incorporation of the Institute.

The following papers were presented by their author:

Biographical Notice of Bruno Kerl, by R. W. Raymond, New York, N. Y.

Biographical Notice of Dr. Thomas M. Drown, by R. W. Raymond, New York, N. Y.

The following paper was presented in abstract by the Secretary, in the absence of its author:

Biographical notice of Sir Lowthian Bell, by Henry M. Howe, New York, N. Y.

The session closed with an informal reception held in the banquet room and parlor of the Arlington.

The second session was held in the lecture room of the Cosmos Club, Wednesday, May 3d, at 9.30 a.m., and was devoted chiefly to papers relating to the metallurgy of iron.

The following papers were presented by their authors and elicited a vigorous and interesting discussion:

The Application of Dry-Air Blast to the Manufacture of Iron, Supplementary Data, by James Gayley, New York, N. Y.

Notes on the Physical Action of the Blast-Furnace, by J. E. Johnson, Jr., Longdale, Va.*

The following papers were distributed in printed form:

Discussion of the paper of James Gayley on "The Application of Dry-Air Blast to the Manufacture of Iron," by Joseph W. Richards, Bethlehem, Pa.

Discussion of the paper of James Gayley on "The Application of Dry-Air Blast to the Manufacture of Iron," by T. W. Robinson, Chicago, Ill.

The third session was held in the lecture-room of the National Museum, Wednesday, May 3d, at 2 p.m., President James Gayley presiding.

A cordial address of welcome was delivered by Dr. Richard Rathbun, Assistant Secretary of the Smithsonian Institution, in charge of the National Museum; and Prof. George P. Merrill, Curator of the Museum, gave a brief outline of the history and development of the Department of Economic Geology. Both addresses will be found in *Bi-Monthly Bulletin*, No. 4, July, 1905.

The following paper was presented by the author and was followed by an animated discussion:

The Manufacture and Characteristics of Wrought-Iron, by James P. Roe, Pottstown, Pa.

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* Presented by title at the Lake Superior meeting, September, 1904 (*Trans.*, xxxv., p. xlv), but manuscript was not received in time for publication in vol. xxxv.

The session adjourned at 4 p.m., and the remainder of the afternoon was profitably spent in viewing the excellent exhibits in the collections of the Museum.

The third session was held at the Cosmos Club, Thursday, May 4th, at 9.30 a.m., Councilor Joseph Hartshorne presiding.

The following paper was presented in oral abstract by Frank Lyman in the absence of the author:

A Machine for Drawing Coke from Bee-Hive Ovens, by George T. Wickes, Covington, Va.

The following papers were presented by the authors:

The Classification of Coals, by Marius R. Campbell, Washington, D. C.

The Copper-Deposits at San Jose, Tamaulipas, Mexico, by Prof. James F. Kemp, New York, N. Y.

The Magmatic Origin of Vein-Forming Waters in Southeastern Alaska, by Arthur C. Spencer, Washington, D. C.

During the sessions the following papers in pamphlet form were distributed:

An Automatic Stock-Line Recorder for Iron Blast-Furnaces, by J. E. Johnson, Jr., Longdale, Va.*

The Outlook for Coal-Mining in Alaska, by Alfred H. Brooks, Washington, D. C.

Gas-Producer Power-Plants, by Samuel S. Wyer, Columbus, Ohio.

The Testing of Gas-Producers, by Samuel S. Wyer, Columbus, Ohio.

Bibliography of Gas-Producers, by Samuel S. Wyer, Columbus, Ohio.

Improved Method of Slag-Treatment at Argo, by Harold V. Pearce, Argo, Colo.

A Special Form of Slag-Car, by L. J. W. Jones and B. H. Bennetts, Tacoma, Wash.

The Effect of Impurities on the Electrical Conductivity of Copper, by Lawrence Addicks, Chrome, N. J.

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* Presented by title at the Lake Superior meeting, September, 1904 (*Trans.*, xxxv., p. xlv), but manuscript was not received in time for publication in vol. xxxv

Repairing Partly Collapsed Cylindrical Furnaces, by John P. Cosgro, Rossland, B. C., Canada.

Tin-Mining and Smelting at Santa Barbara, Guanajuato, Mexico, by A. H. Bromly, Vancouver, B. C.

Labor-Saving Appliances in the Works-Laboratory, by Edward Keller, Baltimore, Md.*

A Summary of Lake Superior Geology, with Special Reference to Recent Studies of the Iron-Bearing Series, by C. K. Leith, Madison, Wis.†

The Occurrence of Stibnite at Steamboat Springs, Nevada, by Waldemar Lindgren, Washington, D. C.

Features of the Occurrence of Ore at Red Mountain, Ouray County, Colorado, by Theodore E. Schwarz, Denver, Colo.

Origin of Orbicular and Concretionary Structure, by William P. Blake, Tucson, Ariz.

Discussion of the paper of David Baker on "Improvements in the Mechanical Charging of the Modern Blast-Furnace," by John J. Porter, Chicago, Ill.‡

Discussion of the paper of David Baker on "Stock-Distribution and its Relation to the Life of a Blast-Furnace Lining," by T. F. Witherbee, Durango, Mexico.§

Discussion of the paper of H. H. Campbell on "The Influence of Carbon, Phosphorus, Manganese and Sulphur on the Tensile Strength of Open-Hearth Steel," by Webster, Dudley, Hunt and Mathews, and reply by Campbell.||

Discussion of the paper of Andrew McWilliam and William H. Hatfield on "Acid Open-Hearth Manipulation," by Morgan and Saniter, and reply by McWilliam and Hatfield.¶

Discussion of the paper of J. M. Gledhill on "The Development and Use of High-Speed Tool Steel," by E. W. Richards,

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* Presented by title at the Lake Superior meeting (see *Trans.*, xxxv., p. xlv), but manuscript was not received in time for publication in vol. xxxv.

† Presented in oral abstract at the Lake Superior meeting, September, 1904 (see *Trans.*, xxxv., p. xliii), but manuscript was not received in time for publication in vol. xxxv.

‡ *Trans.*, xxxv, 1017–1018.

§ *Trans.*, xxxv., 1000–1008.

|| *Trans.*, xxxv., 1043–1048.

¶ *Bi-Monthly Bulletin*, No. 3, May, 1905, pp. 647–649; also *Journal of the Iron and Steel Institute*, vol. lxvi. (1904, No. II.), pp. 218–220.

Howe, Westgarth, Campbell, Mathews, Pye-Smith, J. W. Richards, Oberlin Smith, Carter, Carpenter, Little and Osborn.*

Discusssion of the paper of Jüptner von Jonstorff, Andrew A. Blair, Gunnar Dillner and J. E. Stead, on "Comparison of Methods for the Determination of Carbon and Phosphorus in Steel," by Hamilton and Saniter, and reply by Stead.†

Discussion of the paper of H. A. Guess on "The Commercial Wet Lead-Assay," by Joseph P. Gazzam, and by Arthur Jarman.‡

Discussion of the paper of Charles H. White, on "The Equipment of a Laboratory for Metallurgical Chemistry in a Technical School," by Arthur Jarman.§

Postscript to paper on "Superficial Blackening and Discoloration of Rocks, Especially in Desert Regions," by William P. Blake, Tucson, Ariz.||

The following papers were available for reading in galley-proof form:

Manufacture of Coke in Northern China, by Y. T. Woo, Tong Shan, China.

Discussion of the paper of H. M. Chance on "The Taviche Mining-District near Ocotlan, State of Oaxaca, Mexico," by Edward Halse, Colombia, So. Amer.

The following papers were read by title:

Biographical Notice of Benjamin F. Frazier, by Edward H. Williams, Woodstock, Vt.

The Commercial Value of Coal-Mine Sampling, by Marius R. Campbell, Washington, D. C.

Cyaniding Silver-Gold Ores at the Palmarejo Mine, Chihuahua, Mexico, by T. H. Oxnam, Chinipas, Chihuahua, Mexico.

Genesis of the Ore-Deposits at Bingham, Utah, by J. M. Boutwell, Washington, D. C.

Biographical Notices of 1904.¶

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* *Bi-Monthly Bulletin*, No. 3, May, 1904, pp. 651–665; also *Journal of the Iron and Steel Institute*, vol. lxvi. (1904, No II.), pp 168–181.

† *Bi-Monthly Bulletin*, No. 3, May, 1905, pp. 643–645; also *Journal of the Iron and Steel Institute*, vol. lxvi. (1904, No. II.), pp. 271, 273.

‡ *Trans.*, xxxv., 1010–1014.

§ *Trans.*, xxxv., 971–973.

|| *Trans.*, xxxv., 1017.

¶ *Bi-Monthly Bulletin*, No. 4, July, 1904, pp. 761–786.

The Origin of Vein-Filled Openings in Southeastern Alaska, by Arthur C. Spencer, Washington, D. C.

Present Problems in the Training of Mining Engineers, by Dr. Samuel B. Christy, Berkeley, Cal.*

The Constitution of Mattes Produced in Copper-Smelting, by Allan Gibb and R. C. Philp, Mt. Perry, Queensland, Australia.†

The Occurrence of Pebbles, Concretions and Conglomerates in Metalliferous Mines, by Edward Halse, Puerto Berrio, Colombia, So. Amer.‡

Discussion of the paper of James Gayley, "The Application of Dry-Air Blast to the Manufacture of Iron," by E. Winslow Richards, Raymond, Saniter, Foster, Howe, Thwaite, Pourcel, and reply by Mr. Gayley.§

Discussion of the paper by Robert Schorr, "Fuel and Mineral Briquetting," by E. T. Dumble, Houston, Tex.||

Excursions and Entertainments.

Wednesday evening, May 3d, a visit was made to the Library of Congress by invitation of Mr. Herbert Putnam, the Librarian. Special guides escorted the party and explained in detail the methods of cataloguing and handling the million and more books and manuscripts contained in the many rooms of the Library.

Thursday noon, May 4th, directly after the fourth and final session of the Institute, about 200 members and guests embarked on the steamer *River Queen* for a sail down the Potomac to the Ordnance Proving Grounds, U. S. Navy, at Indian Head. This visit was arranged through the courtesy of Admiral N. E. Mason, Chief of Ordnance, U. S. N., whose representative, Captain Dieffenbach, made the interesting trip all the more enjoyable by his hearty welcome and his personal explanations of

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* Presented at the Lake Superior meeting, September, 1904, under the title, "Problems of American Mining Schools," (see *Trans.*, xxxv., p. xlvi), but manuscript not received in time for publication in vol. xxxv.

† Presented at the Lake Superior meeting, September, 1904 (see *Trans.*, xxxv., p. xlv), but revised proof was not received in time for publication in vol. xxxv.

‡ Presented at the Lake Superior meeting, September, 1904 (see *Trans.*, xxxv., p. xlv), but revised proof was not received in time for publication in vol. xxxv

§ *Trans.*, xxxv., 1022–1042

|| *Trans.*, xxxv , pp 968–971.

the gun-testing plant and its workings. On the return trip up the river a stop was made at Marshall Hall for a "planked-shad" dinner.

Thursday evening, at the invitation of Mr. George A. Post, Chairman of the American Railway Appliances Exhibition, a private view of the Corcoran Gallery of Art and a reception given to the International Railway Congress in the halls of the Gallery were attended by members and guests of the Institute.

Friday, May 5th, was devoted to excursions to various points around Washington. One trip was by the Chesapeake canal to the Great Falls of the Potomac, followed by a visit to the adjacent gold-mines; another was to the naval gun-factory at the U. S. Navy Yard; and a third to historic Mount Vernon. In the evening, the Naval Observatory, through the courtesy of Admiral C. N. Chester, U. S. N., its Superintendent, was thrown open for inspection.

The Cosmos Club and University Clubs, the U. S. Geological Survey and other institutions extended courtesies; and the enjoyment of visiting members was greatly enhanced by the admirable illustrated guide to Washington distributed by the Local Committee as a souvenir.

Members and Guests Registered.

The following list, which is doubtless incomplete, comprises the names registered at hotel headquarters:

Cleveland Abbe, Jr.,	Washington, D. C.
T. H. Aldrich,	Washington, D. C.
Taylor Alderdice,	Pittsburg, Pa.
Mrs. Taylor Alderdice,	Pittsburg, Pa.
Scott Allen,	Philadelphia, Pa.
O. B. Amsden,	Roubaix, S. Dak.
F. E. Bachman,	Port Henry, N. Y.
Mrs. F. E. Bachman,	Port Henry, N. Y.
David Baker,	Philadelphia, Pa.
H. Foster Bain,	Washington, D. C.
Stephen W. Baldwin,	New York, N. Y.
George F. Becker,	Washington, D. C.
John Birkinbine,	Philadelphia, Pa.
A. A. Blow,	Washington, D. C.
W. R. Boggs, Jr.,	Argentina, S. A.
J. M. Boutwell,	Washington, D. C.
John Boyt,	Sparrows Point, Md.
A. H. Brooks,	Washington, D. C.

John C. Bruckenridge,	Brooklyn, N. Y.
Edwin Burkofser,	Woodward, Ala.
M. R. Campbell,	Washington, D. C.
R. H. Chapman,	Washington, D. C.
T. M. Chatard,	Washington, D. C.
Mrs. T. M. Chatard,	Washington, D. C.
F. H. Clement,	New York, N. Y.
W. B. Cogswell,	Syracuse, N. Y.
Albert Law Colby,	New York, N. Y.
George Gordon Crawford,	McKeesport, Pa.
S. W. Croxton,	Cleveland, Ohio.
N. H. Darton,	Washington, D. C.
David W. Day,	Washington, D. C.
Mrs. David W. Day,	Washington, D. C.
Frederic P. Dewey,	Washington, D. C.
Mrs. Frederic P. Dewey,	Washington, D C.
Charles W. Dickson,	Kingston, Can.
Charles E. Dinkey,	Pittsburg, Pa.
Mrs. Charles E. Dinkey,	Pittsburg, Pa.
E. V. d'Invilliers,	Philadelphia, Pa.
James Douglas,	New York, N. Y.
Charles B. Dudley,	Altoona, Pa.
A. Eilers,	Brooklyn, N. Y.
S. F. Emmons,	Washington, D. C.
David L. L. Eynon,	Philadelphia, Pa.
Thomas M. Eynon,	Philadelphia, Pa.
A. W. Fiero,	Chicago, Ill.
H. E Flewellin,	New York, N. Y.
W. H. Fluker,	Thomson, Ga.
Edgar Allen Forbes,	New York, N. Y.
E. L. Foucar,	Denver, Colo.
G. H. Garrey,	Washington, D. C.
James Gayley,	New York, N. Y.
M. I. Goldman,	New York, N. Y.
U. S. Grant,	Evanston, Ill.
Arnold Hague,	Washington, D. C.
Anton Hardt,	Wellsboro, Pa.
C. W. Hardt,	Harrisburg, Pa.
Mrs. C W. Hardt,	Harrisburg, Pa.
Joseph Hartshorne,	Pottstown, Pa.
C. W. Hayes,	Washington, D. C.
Mrs. C. W. Hayes,	Washington, D. C.
J. W. Hoffman,	Philadelphia, Pa.
J. A. Holmes,	St. Louis, Mo.
W. H. Holmes,	Washington, D. C.
Mrs. W. H. Holmes,	Washington, D. C.
W. H. Hughes,	Philadelphia, Pa.
Richard L. Humphrey,	Philadelphia, Pa.
T. M. Jackson,	Clarksburg, W. Va.
J. E. Johnson, Jr.,	Longdale, Va.
W. J. Johnston,	New York, N. Y.
Mrs. W. J. Johnston,	New York, N. Y.

E. S. Jones,	Scranton, Pa.
Edward Keller,	Baltimore, Md.
J. F. Kemp,	New York, N. Y.
C. Kirchhoff,	New York, N. Y.
John Lilly,	Lambertville, N. J.
W. Lindgren,	Washington, D. C.
A. F. Lucas,	Washington, D. C.
Mrs. A. F. Lucas,	Washington, D. C.
Frank Lyman,	Brooklyn, N. Y.
Simon S. Martin,	Sparrows Point, Md.
W. F. Mattes,	Scranton, Pa.
E. C. Means,	Low Moor, Va.
Mrs. E. C Means,	Low Moor, Va.
C. A. Meissner,	New York, N. Y.
George P. Merrill,	Washington, D. C.
Mrs. George P. Merrill,	Washington, D. C.
Franz Meyer,	New York, N. Y.
H. H. Miller,	New York, N. Y.
S. C. Miller,	Washington, D. C.
Mrs. S C. Miller,	Washington, D. C.
Alfred J. Moses,	New York, N. Y.
Charles E. Munroe,	Washington, D. C.
George Ormrod,	Allentown, Pa.
Miss Mary A. Ormrod,	Allentown, Pa.
Edward W. Parker,	Washington, D. C.
Mrs. Edward W. Parker,	Washington, D. C.
H. C. Perkins,	Washington, D. C.
Richard Peters,	Philadelphia, Pa.
Richard Peters, Jr.,	Chester, Pa.
Talbot E. Pierce,	Syracuse, N. Y.
Robert Pitcairn,	Pittsburg, Pa
R. W. Raymond,	Brooklyn, N. Y.
William H. Rea,	Pittsburg, Pa.
Mrs. William H. Rea,	Pittsburg, Pa.
T. A. Rickard,	New York, N. Y.
William Barret Ridgely,	Washington, D. C.
Thomas Robins, Jr.,	New York, N. Y.
Mrs. Thomas Robins, Jr.,	New York, N. Y.
James P. Roe,	Pottstown, Pa.
F. Z. Schellenberg,	Pittsburg, Pa.
Dr. George P. Scholl,	Philadelphia, Pa.
F. C. Schrader,	Washington, D. C.
Mortimer A. Sears,	Mineral, Va.
William L. Sheafer,	Pottsville, Pa.
J. M. Sherrerd,	Easton, Pa.
E. A. Cappelen Smith,	Baltimore, Md.
George Otis Smith,	Washington, D. C.
J. William Smith,	Syracuse, N. Y.
Arthur C. Spencer,	Washington, D. C
J. E. Spurr,	Washington, D. C.
C. E. Stafford,	Chester, Pa.
George Steiger,	Washington, D. C.

B. Stevens,	Valdes, Alaska.
Joseph Struthers,	New York, N. Y.
W. W. Taylor,	Clifton Forge, Va.
Capt. A. Thies,	Charlotte, N. C.
C. H. Tompkins,	Plainfield, N. J.
Mrs. C. H. Tompkins,	Plainfield, N. J.
David Townsend,	Philadelphia, Pa.
Mrs. David Townsend,	Philadelphia, Pa.
Charles D. Walcott,	Washington, D. C.
Mrs. Charles D. Walcott,	Washington, D. C.
W. Irving Walker,	Millington, Md.
Mrs. W. Irving Walker,	Millington, Md.
R. W. Watson,	Harrisburg, Pa.
William R Webster,	Philadelphia, Pa.
Walter Harvey Weed,	Washington, D. C.
Mrs. Walter Harvey Weed,	Washington, D. C.
S. T. Wellman,	Cleveland, Ohio.
Mrs. S. T. Wellman,	Cleveland, Ohio.
Olof Wenstrom,	Boston, Mass.
Marcus White,	Silver City, Idaho.
Prof. E. B. White,	Pittsburg, Pa.
Mrs. E. B. White,	Pittsburg, Pa.
E. C Witherby,	Syracuse, N. Y
N. B. Wittman,	Philadelphia, Pa.
C. F. Wright,	Washington, D. C.
F. E. Wright,	Washington, D. C.
James E. York,	Brooklyn, N. Y.
Frank M. Zeller,	Philadelphia, Pa.

Proceedings of the Eighty-Ninth Meeting, British Columbia, Canada, July, 1905.

COMMITTEES.

Central General Committee —Wm. Fleet Robertson, *Chairman;* Wm. M. Brewer, *Secretary.*

Local Committee of Nelson, B. C.—A. S. Farwell, *Chairman;* W. C. Bayly, *Secretary;* William Blakemore, M. S. Davys, S. S. Fowler, R. R. Hedley, Leslie Hill, A. H. Kelly, W. C E. Koch, J. J. Campbell.

Local Committee of Rossland, B. C.—His Worship Mayor Hamilton, *Chairman;* W H. Aldridge, Charles Biesel, H. H. Claudet, F. W. Guernsey, R. Marsh, J. W. Astley, R. W. Brock, A. A. Cole, A. G. Larsen, R. H. Stewart. Also the *Rossland Board of Trade,* Robert Hunter, *President;* K. E Mackenzie, *Vice-President;* A. B. Mackenzie, *Secretary.*

Local Committee of Grand Forks, B. C.—His Worship Mayor Hammor, *Chairman;* A. W. B. Hodges, A. L. White, G. M. Fripp, L. A. Manley, W. T. Spier, G. W. Wooster.

Local Committee of Victoria, B. C.—Wm. Fleet Robertson, *Chairman;* William M. Brewer, *Secretary;* Harold Grant, Thomas Kiddie, Clermont Livingston, E. C Musgrave, W. J. Sutton, Francis A. Thomson.

Local Committee of Vancouver, B. C.—C. F. Jackson, *Chairman;* His Worship Mayor F. Buscombe, J. J. Banfield, A. Bethune, John Boyd, H. C. Clarke, A. B. Erskine, E. P. Gilman, William Godfrey, W. D. Haywood, R. K. Houlgate, H. T. Lockyer, J. Y. McAdam, H. M. McDowell, C. W. McMeekin, W. H. Malkin, F. Richards, T. J. Smith, George A. Walkem, G. Sheldon Williams

Local Committee of White Horse, Y T.—Robert Lowe, *Chairman;* T. W. Jackson, *Secretary;* George Armstrong, A. L. Bindley, Rev. Father Corbeil, L. De Gex, A. E. Fisher, W. P. Grainger, P. D. McMillan, Rev. Mr. Main, George C. Mallot, Alfred Parre, George Pulham, George Reid, William Robinson, J. P. Scharschmidt, J. C. Schraeder, Major A. E. Snyder, Rev. Mr. Stringer, Judge George L. Taylor, William Taylor, H Wheeler, E. J. White, J. P. Whitney.

Local Committee of Dawson, Y. T.—Hon. W.W. B. McInnes, Commissioner of the Yukon Territory, *Honorary Chairman;* Major Z. T. Wood, Assistant Commissioner of the Yukon Territory, *Honorary Chairman;* J B. Tyrrell, *Chairman;* J. Moore Elmer, *Vice-Chairman;* George Black, *Secretary;* Hon. Mr. Justice Dugas, Hon. Mr. Justice Macaulay, Hon. Mr. Justice Craig, Dr. Alfred Thompson, D. A. Cameron, E. W. Griffin.

The first session, held in the ministers' room of the Parliament Building, 3 p.m., Saturday, July 1st, was presided over by Past-President Robert W. Hunt. His Excellency the Lieut.-

Governor Sir Henri Joly de Lotbinière was introduced by Mr. Wm. Fleet Robertson, Chairman of the Local Committee, and, in a few well-chosen remarks, extended a cordial welcome to the visiting members and guests of the Institute.

Hon. Richard McBride, Premier and Minister of Mines, was next introduced, and, reiterating the cordial sentiments of Sir Henri, gave a double welcome to the Institute. To these addresses Mr. Hunt responded.

Mr. W. J. Sutton gave an informal lecture on the geology and mineral resources of Vancouver Island, Victoria, B. C.*

The following papers were presented by their authors in oral abstract:

Smelting Copper-Ore Having a Large Percentage of Zinc, by Thomas Kiddie, Ladysmith, B. C.*

Mechanical Charging of Copper Blast-Furnaces at Grand Forks, B. C., Canada, by A. B. W. Hodges, Grand Forks, B. C.*

On Saturday evening a public reception was given in the Parliament Buildings.†

On Monday, July 3d, a steamer-excursion among the islands off the coast of Vancouver island was given by the Victoria Board of Trade.†

On Tuesday, July 4th, excursions were made to the mine of the Tyee Copper Co., at Mt. Sicker, and the smelting-works of the same company at Ladysmith.†

The second session was held at the same place, 10 a.m., Wednesday, July 5th, Past-President Robert W. Hunt presiding.

The following papers were presented in oral abstract by their authors:

The Geology of Deutschman's Cave near Glacier, Alberta, by W. S. Ayres, Banff, Alberta, Can. (illustrated with lantern).‡

Geological Mine-Maps and Sections, by D. W. Brunton, Denver, Colo.

Kernel Roasting, by Herman Poole, New York, N. Y.

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* Not furnished for publication.

† In addition to this formal record, a more particular account of all excursions and entertainments will be found in the general narrative prepared by the Secretary, and printed below.

‡ Publication postponed to await the results of more extensive local exploration by the author.

The third and concluding session was held at 3 p.m. of the same day.

Mr. Wm. M. Brewer, of Victoria, gave an informal account of the mineral resources of the coast from Vancouver to Skagway, and a brief description of the geology of the country along the railroad from Skagway to White Horse and along the Yukon river from White Horse to Dawson.

The following papers were read by title:

Genetic Relations of the Western Nevada Ores, by J. E. Spurr, Washington, D. C.

Are the Quartz-Veins of Silver Peak, Nevada, the Result of Magmatic Segregation? by John B. Hastings, Denver, Colo.

The Electrolytic Assay of Lead and Copper, by George A. Guess, Silverton, Colo.

Anthracite Washeries, by George W. Harris, New York, N.Y.

The Importance of Fine Grinding in the Cyanide Treatment of Gold- and Silver-Ores, by Frederick C. Brown, Auckland, New Zealand.

Lead- and Zinc-Deposits of the Virginia-Tennessee Region, by Thomas Leonard Watson, Blacksburg, Va.

The Limestone-Granite Contact-Deposits of Washington Camp, Arizona, by W. O. Crosby, Boston, Mass.

The Use of High Percentages of Fine Ore in a Charcoal Blast-Furnace, by Harry R. Hall, Kent, Ohio.

Cost Accounts of Gold-Mining Operations, by Thomas H. Sheldon, Victor, Colo.*

Notes on Southern Nevada and Inyo County, California, by H. H. Taft, Denver, Colo.*

The Origin of Clinton Red Fossil-Ore in Lookout Mountain, Alabama, by William M. Bowron, Chattanooga, Tenn.

Blast-Furnace Practice. A Discussion of the paper of James Gayley, "The Application of Dry-Air Blast to the Manufacture of Iron," and that of J. E. Johnson, Jr., "Notes on the Physical Action of the Blast-Furnace," by Charles B. Dudley, R. W. Raymond, J. E. Johnson, Jr., William F. Mattes, James Gayley, David Baker, John Birkinbine and F. E. Bachman.

Reply to Discussion by Arthur Jarman of the paper, "Equipment of a Laboratory for Metallurgical Chemistry in a Technical School," by Charles H. White, Cambridge, Mass.

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* Manuscript not received in time for publication in this volume.

Discussion of the paper of H. O. Hofman, "The Effect of Silver on the Chlorination and Bromination of Gold," by T. K. Rose, London, England.

Discussion of the paper of James P. Roe, "The Manufacture and Characteristics of Wrought-Iron," by C. Edward Stafford, Allerton S. Cushman, Charles B. Dudley, Joseph Hartshorne, N. B. Wittman, and reply by Mr. Roe.

Discussion of the paper of H. H. Campbell, "The Influence of Carbon, Phosphorus, Manganese and Sulphur on the Tensile Strength of Open-Hearth Steel,"* by Mansfield Merriman, South Bethlehem, Pa.

Discussion of the paper of H. M. Chance, "The Taviche Mining-District near Ocotlan, State of Oaxaca, Mex.,"† by Edward Halse, Puerto Berrio, Colombia, So. Amer.

Discussion of the paper of James P. Roe, "The Manufacture and Characteristics of Wrought-Iron," by Taylor Allderdice, Pittsburg, Pa.

On Wednesday evening, a social reception was given by Lieut.-Gen. Sir Henri Joly de Lotbinière, at the Government House; and during the night, the members and guests of the Institute left Victoria for Vancouver.

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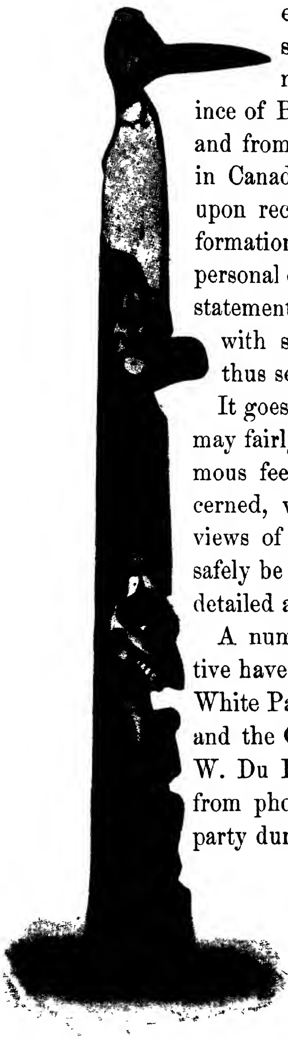
* *Trans.*, xxxv., 772.

† *Trans*, xxxv., 886.

EXCURSIONS IN BRITISH COLUMBIA, ALASKA AND THE YUKON TERRITORY.

BY R. W. RAYMOND, SECRETARY OF THE INSTITUTE.

The following narrative has been prepared for the purpose of furnishing to those who did not take part in the journey described some notion of its interest and pleasure; of acknowledging the abundant and manifold courtesies received by the party from the governments of the Dominion of Canada, the Province of British Columbia and the Yukon Territory, and from corporations, firms and individual citizens in Canada and the United States; and of placing upon record a portion, at least, of the valuable information gained by members of the party through personal observation and inquiry, or from the official statements furnished by local committees, together with some impressions, produced by what was thus seen, heard or read.

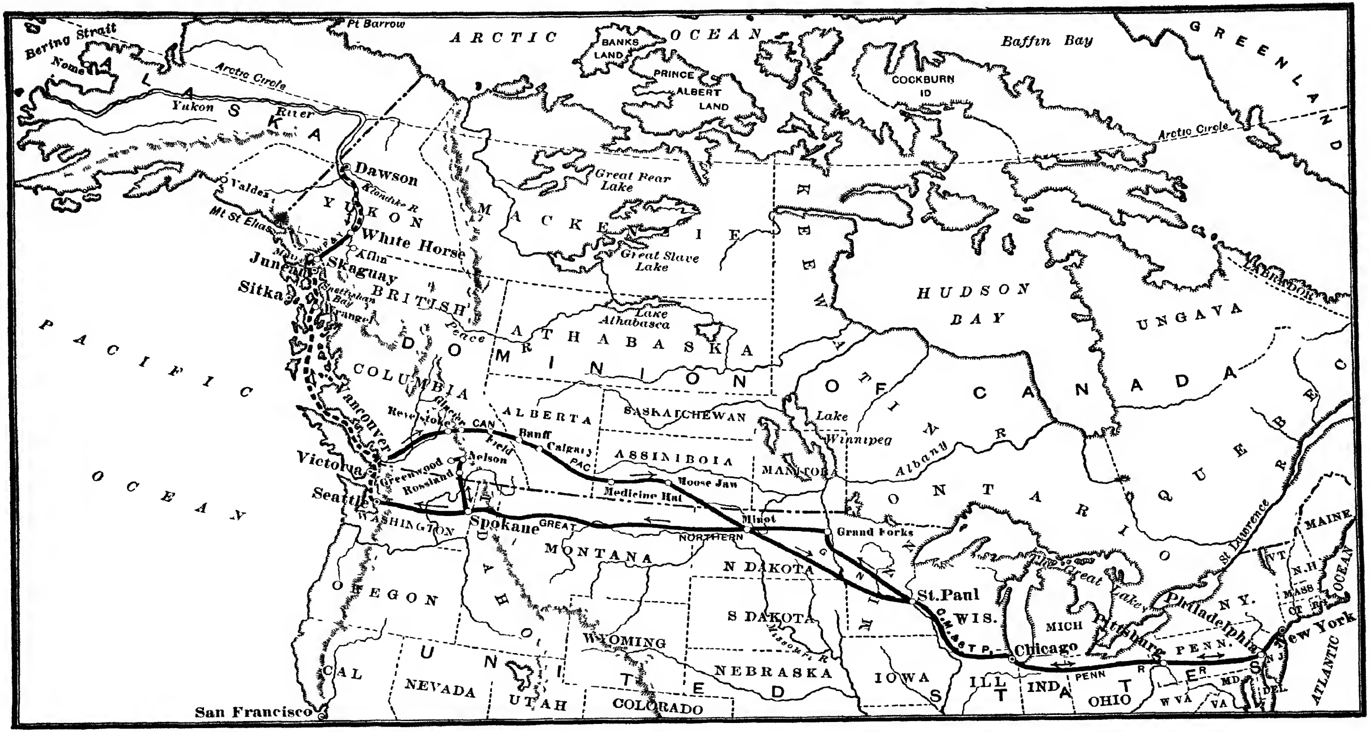


Totem Pole at Ketchikan, Alaska.

It goes without saying that parts of this narrative may fairly be considered as representing the unanimous feeling of the members of the Institute concerned, while other parts express the individual views of the writer only. Intelligent readers may safely be trusted to make this distinction, without detailed and specific guidance.

A number of the illustrations used in this narrative have been obtained through the courtesy of the White Pass & Yukon railway, Great Northern R. R. and the Canadian Pacific railway; others from H. W. Du Bois, of Philadelphia; and the remainder from photographic views made by members of the party during the trip.

On Friday, June 22d, at 8.15 a.m., members and guests of the Institute residing in New York and vicinity left Jersey City, N. J., via the Pennsylvania railroad, in a special Pullman train, compris-



Bering Strait
Nome
Pt Barrow
ALASKA
Arctic Circle
Yukon River
Valdes
Mt St Elias
Dawson
Klondike R
YUKON
White Horse
Atlin
Skaguay
Juneau
Sitka
Wrangel
ARCTIC OCEAN
BANKS LAND
PRINCE ALBERT LAND
COCKBURN ID
Baffin Bay
GREENLAND
MACKENZIE
Great Bear Lake
Great Slave Lake
KEEWATIN
HUDSON BAY
UNGAVA
LABRADOR
BRITISH COLUMBIA
Peace
ATHABASKA
Lake Athabasca
DOMINION OF CANADA
ALBERTA
SASKATCHEWAN
ASSINIBOIA
MANITOBA
Lake Winnipeg
Albany R
ONTARIO
QUEBEC
St Lawrence
PACIFIC OCEAN
Revelstoke
Glacier
CAN
Field
Banff
Calgary
PAC
Vancouver
Victoria
Greenwood
Rossland
Nelson
Medicine Hat
Moose Jaw
Seattle
WASHINGTON
Spokane
GREAT NORTHERN
Minot
Grand Forks
MONTANA
N DAKOTA
St.Paul
WIS.
C.M.&ST.P.
Chicago
MICH
Great Lakes
Pittsburg
Philadelphia
N.Y.
PENN.
New York
MAINE
VT.
N.H.
MASS
CT
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N.J.
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ATLANTIC
OREGON
IDAHO
WYOMING
S DAKOTA
Missouri R
NEBRASKA
IOWA
ILL
INDA
OHIO
PENN R R
UNITED STATES
CAL
NEVADA
UTAH
COLORADO
San Francisco

ITINERARY.

Mileage.	Place.	Day.	Time.	Route.
	New York	Lv Friday,	June 23rd, 7.55 a.m.	
0	Jersey City	Lv Friday,	" 23rd, 8.16 a.m.	Pennsylvania R R.
	Philadelphia	Lv. Friday,	" 23rd, 10.25 a m.	
	Harrisburg	Lv. Friday,	" 23rd, 12.55 p m.	
	Pittsburg	Lv Friday,	" 23rd, 7 05 p m.	
912	Chicago	Arr. Saturday,	" 24th, 7.40 a.m.	
	Chicago	Lv. Saturday,	" 24th, 9 50 a.m.	C. M. & St. P.
410	St. Paul	Arr. Saturday,	" 24th, 10 00 p.m.	
	St Paul	Lv Saturday,	" 24th, 1.30 a.m.	Great Northern R R.
1490	Spokane	Arr Monday,	" 26th, 11.00 p m.	
	Spokane	Lv. Monday,	" 26th, 9 30 p m.	Great Northern R. R system.
200	Nelson	Arr Tuesday,	" 27th, 11 00 a.m.	
50	Kootenai Lake			St. " Kaslo."
	Nelson	Lv. Tuesday,	" 27th, 11 30 p m.	Great Northern R.R. system
89	Rossland	Arr Wednesday,	" 28th, 10.15 a m	
15	Trail Creek	Wednesday,		Can. Pac. R.R system
	Rossland	Lv. Wednesday,	" 28th, midnight.	Great Northern R.R system.
87	Grand Forks	Arr. Thursday,	" 29th, 8 00 a.m	
	Phœnix	Thursday		Great Northern R R system
63	Grand Forks	Lv Thursday,	" 29th, 11 30 p m	
143	Spokane	Arr Friday,	" 30th, 7 10 a.m	
	Spokane	Lv. Friday,	" 30th, 8 00 a.m.	Great Northern
339	Seattle	Arr Friday,	" 30th, 8 30 p m.	
	Seattle	Lv Friday,	" 30th, midnight	Str " Princess Victoria."
78	Victoria	Arr Saturday,	July 1st, 6 00 a m.	
100	Harbor Excursion	Saturday,		Str. " Charmer "
100	Mt Sicker and Ladysmith			Esquimault & Nanaimo R R
	Victoria	Lv. Thursday,	" 6th, 2 00 a m	St. "Princess May."
84	Vancouver	Arr Thursday,	" 6th, 9 00 a m.	
	Vancouver	Lv. Friday,	" 7th, 5 00 a.m	
867	Skaguay	Arr Monday,	" 10th, 6 00 a m	
	Skaguay	Lv Monday,	" 10th, 10 30 a. m.	W P & Y. R
110	White Horse	Arr Monday,	" 10th, 4 30 p m	
	White Horse	Lv Tuesday,	" 11th, 2 00 a m	Strs " Selkirk " and " Dawson."
450	Dawson	Arr Wednesday,	" 12th, 4 00 p.m	Stages
40	Around the " Dome "	Thursday,	" 13th,	
		Friday,	" 14th,	
	Dawson	Lv Saturday,	" 15th, midnight.	Str. "White Horse" and " Dawson "
450	White Horse	Arr. Wednesday,	" 19th, 6 00 a.m	
	White Horse	Lv Wednesday,	" 19th, 9 30 a. m.	W. P. & Y. R.
110	Skagway	Arr. Wednesday,	" 19th, 3 00 p.m	
	Skagway	Lv. Wednesday,	" 19th, 9 00 p.m.	Str. " Princess Beatrice."
867	Vancouver	Arr. Sunday,	" 23rd, a m	
	Vancouver	Lv. Sunday,	" 23rd, 12 00 noon	Can. Pacific R R
422	Glacier.	Arr Monday,	" 24th, 6 55 a.m	
	Glacier.	Lv Monday,	" 24th, 12.00 noon	" " "
88	Field.	Arr Monday,	" 24th, 4 45 p m.	
	Field	Lv Monday,	" 24th, 6 00 p m	" " "
16	Laggan.	Arr Monday,	" 24th, 7 30 p m.	
	Laggan.	Lv. Tuesday,	" 25th, 4 00 p m	" " "
34	Banff	Arr. Tuesday,	" 25th, 5 10 p.m	
	Banff	Lv. Wednesday,	" 26th, 4 00 p m	" " "
82	Calgary	Lv. Wednesday,	" 26th, 8.00 p m	Can. Pacific
442	Moose Jaw	Lv. Thursday,	" 27th, 12 30 p m	" "
168	Portal	Lv. Thursday,	" 27th, 6.30 p m	M. S P & S S. M.
560	St. Paul	Arr. Friday,	" 28th, 2.05 p.m	
	St. Paul	Lv Friday,	" 28th, 8 50 p m.	C. M. & St. P.
410	Chicago	Arr. Saturday,	" 29th, 9.15 a m	
	Chicago	Lv. Saturday,	" 29th, 1 30 p m	Pennsylvania R R.
912	Jersey City	Arr. Sunday,	" 30th, 2.50 p m	
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The itinerary of the trip is traced on the map, on the opposite page, the solid lines showing the route by railroad and the broken line the routes by coastwise steamer and river steamboat.

ing the following cars: "China" (1 drawing-room, 1 state-room and 12 sections); "Australia" (1 drawing-room, 1 state-room and 12 sections); "Deioces" (2 drawing-rooms and 10 sections); "Guiana" (compartment-car, 2 drawing-rooms and 7 state-rooms); "Hollenden" (dining-car); the private car "Olympia," famous through its use by the late President McKinley, Prince Henry, and other notables (3 drawing-rooms, 2 large state-rooms, and a large reception-room used alternately as a special dining-room and as a general lounging and smoking-room for the men of the party); also a large Pennsylvania railroad (Adams' Express) baggage-car. In addition to this train, which carried the party across the continent to Seattle (including the excursion into the Kootenai region in British Columbia), back from Vancouver to Jersey City, there had been also secured a special train from Nelson, B. C., to Bonnington Falls and return; a special train from Rossland to Trail Creek and return; the steamboat "*Kaslo*" for the trip on Kootenai lake; the steamer "*Charmer*" for the harbor excursion from Victoria; a special train from Victoria to Ladysmith and return; three ocean steam-ships (the "*Princess Victoria*" for the passage from Seattle to Victoria, and from Victoria to Vancouver; the "*Princess May*" for the sea-trip from Vancouver to Skagway, and the "*Princess Beatrice*" for the return trip from Skagway to Vancouver); a special train across White Pass, between Skagway and White Horse, both going and returning; the river steam-boats "*Dawson*" and "*Selkirk*," for the trip down the Yukon river to Dawson; and the "*White Horse*" and "*Dawson*," for the return to White Horse.

The whole journey, covering more than 10,000 miles, occupying 38 days, and involving, at different times, as explained above, the use of six different special trains and nine steamers, was accomplished without mishap or discomfort—a result largely due to the thorough arrangements made beforehand by Mr. Theodore Dwight, who organized the excursion, and to the executive management *en route*, in which he was ably assisted by Mr. A. E. Vaughan. Special acknowledgment should also be made of the efficient services of Mr. John Downs, an experienced baggage-master detailed from the Phila., Wilmington and Baltimore division of the Pennsylvania railroad, who accompanied the party throughout; superintended the transfer of

its baggage, large and small, at every change from train to hotel or steamer, or *vice versa;* brought back the whole collections (somewhat increased by purchases of antlers, totem-poles, etc.) without the loss of a single piece; and, most wonderful and agreeable of all, made it possible for the travelers at any reasonable time, on land or sea, to have convenient access to their trunks. The importance of this luxury, upon a tour through such varieties of altitude, latitude, and climate, can scarcely be over-estimated. For ladies especially, the ability to walk easily through a vestibuled train, and to take from, or return to, their trunks in the baggage-car whatever they chose, removed the greatest inconvenience of travel, by making it unnecessary to cumber state-rooms and sections with bags and bundles, containing provision for the ordinary or contingent exigencies of a long journey.

The following list contains the names of those constituting the special excursion-party:

Roster of Special Excursion Party.

Mr. W. P. Agnew	New York, N Y.
Mr. T. H. Aldrich	Washington, D. C.
Mrs. T. H. Aldrich	Washington, D. C.
Miss Aldrich	Washington, D. C.
Mrs. M. B. Ayres	Bound Brook, N. J
Mrs. S. Ayres	Bound Brook, N. J.
Mr. W. S. Ayres	Banff, Alberta, Can.
Mrs. W. S. Ayres	Banff, Alberta, Can.
Mr. D. W. Brunton	Denver, Colo.
Mrs. D. W. Brunton	Denver, Colo.
Miss Pearl Browning	Syracuse, N. Y.
Miss Elizabeth Browning	Syracuse, N. Y.
Miss J. Butchart	Victoria, B. C.
Mr. Joseph G. Butler	Youngstown, Ohio.
Mrs. Joseph G. Butler	Youngstown, Ohio.
Mr. S. M. Bamberger	Salt Lake City, Utah
Mr. G. D. Barron	Rye, N. Y.
Mrs. G. D. Barron	Rye, N. Y.
Miss Dorothy Barron	Rye, N. Y.
Miss M. E. Barron	Rye, N. Y.
Mr. David Briggs	Chicago, Ill.
Mrs. David Briggs	Chicago, Ill.
Mr. F. J. Campbell	Denver, Colo.
Mrs. F. J. Campbell	Denver, Colo.
Mr. A. E. Carlton	Cripple Creek, Colo.
Mrs. A. E. Carlton	Cripple Creek, Colo.
Mr. F. H. Clymer	Reading, Pa.

Mr. W. B. Cogswell	Syracuse, N. Y.
Mrs. W. B. Cogswell	Syracuse, N. Y.
Mr. E S. Cook	Pottstown, Pa.
Mrs. E. S. Cook	Pottstown, Pa.
Mr. Richard Cook	Pottstown, Pa.
Master Cook	Pottstown, Pa.
Mr. J. B. Cullum	Pittsburg, Pa.
Mr. Theodore Dwight	New York, N Y.
Mr. E. V. d'Invilliers	Philadelphia, Pa.
Mrs. E. V. d'Invilliers	Philadelphia, Pa.
Miss d'Invilliers	Philadelphia, Pa.
Mr. B. F. Fackenthal, Jr.	Easton, Pa.
Mrs. B. F. ~~Fackenthal~~, Jr.	Easton, Pa
Mr. D. G. Forbes	Shillingstone, Blandford, Eng.
Mr. E. L. Ford	Youngstown, Ohio.
Mr. John Ford	Youngstown, Ohio
Mr. E. L. Foucar	Denver, Colo.
Mrs. E L Foucar	Denver, Colo.
Mr. F. T. Freeland	Philadelphia, Pa.
Mr. C W Goodale	Butte, Montana.
Mr. J. C Gwillim	Kingston, Ontario, Can.
Mr. M. H. Harrington	Philadelphia, Pa.
Mrs M H. Harrington	Philadelphia, Pa
Miss M L Harrington	Philadelphia, Pa.
Mr. Arthur Harrington	Philadelphia, Pa.
Mr. A B W Hodges	Grand Forks, B. C, Can
Mrs A B W Hodges	Grand Forks, B. C., Can.
Mr. L. Holbrook	New York, N. Y.
Mrs. L Holbrook	New York, N. Y
Mr. Holt	Macon, Ga
Miss Ida Holt	Macon, Ga.
Mrs. J. R Howard	Brooklyn, N. Y
Mr R. W Hunt	Chicago, Ill.
Mrs. R. W. Hunt	Chicago, Ill.
Captain John Irving	Victoria, B Can
Mr John C. Kafer	New York, N. Y.
Mr. Paul S. King	New York, N. Y
Mr S. F Kirkpatrick.	Kingston, Ontario, Can
Mr. J. Laidlaw	Cranbrook, B. C., Can.
Mrs. James M. Lawton	New York, N. Y
Mr. John Lilly	Lambertville, N. J.
Mrs. John Lilly	Lambertville, N. J.
Mr Wm. Lilly	Lambertville, N J.
Major Charles E Lydecker	New York, N. Y.
Mr. F. W. Lyman	Minneapolis, Minn.
Mr George R. Lyman	Minneapolis, Minn.
Mr. Wm. R. McIlvain	Reading, Pa.
Mrs. Wm. R. McIlvain	Reading, Pa.
Miss Anna W. ~~Olcott~~	New York, N. Y.
Mr. Chas. T. Olcott	New York, N. Y.
Master Mason Olcott	New York, N. Y.
Mr. I. P. Pardee	Hazelton, Pa.

Mrs. I. P. Pardee	Hazelton, Pa.
Master James Lee Pardee	Hazelton, Pa.
Mr. W. S. Pilling	Philadelphia, Pa.
Mrs. W. S. Pilling	Philadelphia, Pa.
Miss Mary B. Pilling	Philadelphia, Pa.
Mr. Joseph Ross Pilling	Philadelphia, Pa.
Mr. George Pilling	Philadelphia, Pa.
Dr. R. W. Raymond	Brooklyn, N. Y.
Mrs. R. W. Raymond	Brooklyn, N. Y.
Gen. Chas. F. Roe	New York, N. Y.
Mrs. Chas. F. Roe	New York, N. Y.
Miss Ross	Macon, Ga.
Miss Ella Sealy	Galveston, Tex.
Miss Rebecca Sealy	Galveston, Tex.
Dr. Joseph Struthers	New York, N. Y.
Miss Florence Starr	Brooklyn, N. Y.
Miss Velasquez	New York, N. Y.
Mr. A. E. Vaughan	Brooklyn, N. Y.
Mr. Walter Wood	Philadelphia, Pa.

In addition to these persons, many local members and guests attended the sessions at Victoria, and accompanied the party on various excursions and for limited distances along the route.

The schedule and the accompanying map, given on pages lviii and lix, show the places and routes concerned in this journey.

Totem at Ketchikan, Alaska.

Spokane.

Arriving at Spokane, Wash., on Monday, June 26th, at 8.40 p.m., the party was hospitably received by the Board of Trade of that beautiful and prosperous city, and an hour was agreeably and profitably spent in the inspection of the handsome streets and buildings of which the citizens of Spokane are so justly proud, the Spokane Falls and the machinery by which they are utilized for motive power, illumination, etc.; the up-to-date fire-department, etc. Unfortunately, the lateness of the hour prevented a tour through the beautiful residential section

Nelson, British Columbia.

of the city and its Park—both of which were remembered by many who had visited Spokane on a similar Institute excursion in 1899. An informal reception and collation at the railway station appropriately concluded this brief but cordial entertainment.

The Kootenay Region.

At 9.30 p.m., June 26th, the party left Spokane by the Spokane Falls and Northern branch of the Great Northern Railway, and, after crossing the International Boundary (a few miles beyond Northport, Wash.), proceeded over the Nelson and Fort Sheppard Railway, through the Ymir gold-mining

district, to Nelson, B. C., which was reached at 11 a.m., June 27th. Messrs. S. S. Fowler, Leslie Hill, R. R. Hedley and other members of the Local Reception Committee escorted the party to the steamer "*Kaslo*," which, decorated with flags, awaited them at the city wharf, and conveyed them through the picturesque "West Arm" of the Kootenay to Proctor's, at the entrance into the main lake, where an open-air luncheon was served; after which, before returning to Nelson, a brief voyage was made upon the Kootenay lake itself.

Bonnington Falls, near Nelson, British Columbia.

It is difficult to describe in words the exquisite loveliness and charm of this region. Coming after the long railway journey, the peace and loveliness of these lakes and rivers were, no doubt, doubly impressive. Yet no such additional emphasis was needed to enforce their enthralling charms. Neither the Swiss nor the Italian lakes can be considered as surpassing those of this district—each a perfect turquoise, set in hills of emerald, and spanned by an opalescent sky. The curious interlocking of the two drainage-systems of the Kootenay and the Columbia, with their respective enlargements into lakes, contractions into rapids and cascades, and ramifications in innumerable mountain

streams, presents a topographical complex for which it would be difficult to find a parallel. The Kootenay country is well worth a pilgrimage on account of its scenery alone. But its rich mines were the original cause of its development, and remain the basis of its prosperity. The water-ways are utilized, in connection with connecting railroads, for the transportation of ore and coal to the smelters; the water-falls offer abundant power, to be utilized and transmitted by electric currents; and the climate does not prevent continuous mining throughout the year. In the immediate neighborhood of Nelson, no large mines have been opened; and the smaller operations which might become important, have been handicapped by hasty and sweeping legislation, such as the passage of an "eight-hour law" for British Columbia. Quite apart from the question of the wisdom of such laws, as applied to large and profitable undertakings, it must be at once confessed that they operate most cruelly upon enterprises engaged in "dead-work," or not yet on a paying basis. Any arbitrary prohibition, in such cases, of the employment of cheaper labor, or the employment of men who volunteer to work for more than eight hours a day, simply shuts up the mines which might otherwise develop into great producers. Such hasty and indiscriminate legislation has inflicted upon the mining districts of British Columbia much injury, from which they are but slowly recovering. In the vicinity of Nelson, a very healthy and encouraging sign may be recognized, in the operation of small mines upon a system of "tribute" or contract, under which operations are directed by the skilled engineer of the proprietor, while the whole working-force is paid, in the lump, at an agreed rate for the amount of excavation performed, or the amount of ore produced. This total payment is divided among the workmen as they choose. It is generally understood that all the skilled miners are paid alike, without reference to the actual product of their labor. But nobody can find out what wages each man receives, because his receipts are not in wages; and nobody can say for how many hours a day the work goes on, because the men thus contracting as a body to operate a given mine will not tell anybody, or permit any walking-delegate to find out by inspection, how long they choose to work. All that is known, therefore, is that a number of mines thus operated are paying profits to the owners

for the first time in their history, while the working miners are receiving for their labor more than ever before.

Returning to Nelson in the afternoon, the party was conveyed on a special train furnished by the Canadian Pacific railway, to Bonnington Falls, on the Kootenay river. Here the interesting power-plant of the West Kootenay Power and Light Co. was inspected, and a picnic dinner, provided by the ladies of Nelson, was heartily enjoyed, after which the train returned to Nelson. During the evening, many of the gentlemen were cordially entertained at the Nelson Club, and at a late hour the special train departed for Rossland.

Rossland.

Arriving at Rossland at 9.45 o'clock on Wednesday morning, June 28th, the visitors were cordially received by the representatives of the Local Committee.

In view of the limited time which could be given to the inspection of the many interesting and important mines and works of the district, separate parties were organized, to visit respectively the Centre Star and the War Eagle mines, the Le Roi and Le Roi No. 2 concentrating-works (at the latter of which, Mr. H. H. Claudet, of the Canadian Ore Concentration Co., exhibited and explained the Elmore "oil-process" of concentration, there in use), or to drive about the city and along the mountain road to the site of the old Columbia and Kootenai mine, commanding a magnificent view of the Columbia river, the Trail smelter, the valley from Rossland to Trail, and the misty mountains which frame that picture.

At 1 o'clock, a rendezvous was made at the War Eagle hotel, on the mountain, where luncheon was served; and at 2.30 p.m. a special train conveyed the party to the Trail smelting-works of the Canadian Pacific Railway Co. In the absence of Mr. Walter H. Aldridge, chief of the mining and metallurgical department of that company, the visitors were received by Mr. J. Labarthe, Superintendent of the works, and his assistants, under whose courteous and intelligent guidance an hour or two passed quickly in the inspection of the smelting-furnaces, the electrolytic lead-refinery, and the plant for making lead-pipe. The explanation of Mr. Aldridge's much-regretted absence was furnished soon after by the announcement in the newspapers of

the purchase by him, for a syndicate understood to represent the Canadian Pacific interest, of the control of three of the principal producing mines of the region. The result of this important acquisition was generally expected to be a saving in the management and a larger output from the mines concerned, and a corresponding gain in the product and technical economy of the works at Trail.

Through the courtesy of the Rossland Board of Trade, each visitor received a copy of the very able paper of Mr. Edmund B. Kirby, a member of the Institute, and lately manager of the Center Star and War Eagle mines, on "The Ore-Deposits of Rossland." From this paper (originally published in the *Journal of the Canadian Mining Institute*, vol. vii., March, 1904) the following statement has been condensed:

The Rossland district began active production in 1894, and up to January 1, 1904, yielded 1,620,540 tons of smelting-ore, of the gross value of about $26,000,000, or $16 per ton in gold, silver and copper. Of this total, about 1,500,000 tons were shipped by four mines, the Le Roi, War Eagle, Centre Star and Leroi No. 2.

The geology of the district is peculiar. It presents an oval area of gabbro, constituting the central mass of a very ancient volcano, crystallized at great depths and now exposed by erosion, and surrounded by successive alternating bands of porphyrites and diabases, tuffs and slates The porphyrites belong to the same magma as the gabbro, from which they are separated by an indefinite boundary (practically a zone of transition), and contain, near this boundary, the principal mines These are located on Red mountain, above the town of Rossland, and at the west end of the gabbro mass, on which the town stands. The porphyritic country-rock is cut by numerous dikes and faults.

The veins are "shear-zones," produced by movement under high pressure, and subsequently mineralized, by replacement or impregnation. The chief ore-mineral is pyrrhotite, accompanied in places by small proportions of chalcopyrite, pyrite and arsenopyrite. These minerals, which were mainly introduced later than the original pyrrhotite, give commercial value in copper, gold and silver to the ore. Ore thus enriched occurs in shoots, of which several have been extensively worked. The product of the mines is concentrated in jigs, buddles, etc., and shipped for metallurgical treatment to the large smelting-works at Trail and Northport.

An encouraging feature of the larger mines is the continuity of ore to the lower levels (down to 1,550 ft. at present), and its greater value there than above.

The history of the Rossland district presents many vicissitudes, due to speculative recklessness, loose management, exorbitant labor-cost, and ignorance of the peculiar geological conditions of the ore-deposits and the treatment required by the

ores. These causes have in large measure passed away. It is recognized that mining must be done on a large scale, with abundant capital for machinery, concentration-works, etc., and that the product must be treated at large establishments, where the advantages of mixture with other ores can be realized. The management of the large mines is careful and efficient; and their present condition gives promise of a considerable period of uninterrupted and profitable production. The chief cloud upon the future of the district is the high cost of prospecting and dead-work, which checks the exploration, by enterprising small capitalists, of the undeveloped ground or the mines which do not yet pay. While the maintenance of a few large concerns undoubtedly gives the best guaranty of continued production, it is the activity of many small undertakings which contribute most to the healthy prosperity of a mining camp, and leads to those discoveries and developments which assure its future. The Provincial laws and the labor-union rules which now treat all mining enterprises alike, as if all were equally able to bear the same rate of expense, might well be so modified as to favor operations not yet profitable; for these operations need, and will repay, encouragement. The number, in the Rossland district, of mines once operated, but now temporarily abandoned, and the area of promising ground not yet adequately explored, bear significant testimony on this point.

In the evening, a banquet was given by the Local Committee at the Hotel Allan. Mr. Charles Robert Hamilton, the Mayor of Rossland, presided, and after toasts to "The King" and "The President," proposed "Our Guests," with a graceful address of welcome, to which Mr. Robert W. Hunt, past President, and, on this journey, acting President, responded. Interesting and eloquent addresses were subsequently made, on the part of the hosts of the occasion, by Hon. J. A. Macdonald, K. C., M. P. P., Prof. R. W. Brock of the Canadian Geological Survey, Mr. Anthony J. McMillan, general manager of the Le Roi mine, Mr. A. A. Cole, of the engineering staff of the Centre Star and War Eagle, Mr. William Fleet Robertson, Provincial Mineralogist of British Columbia, and Messrs. A. S. Goodeve and A. B. Mackenzie, of the Local Committee; and, on the part of the guests, by Maj. Chas. E. Lydecker and R. W. Raymond, of

New York City. At a late hour, after the singing of "Auld Lang Syne," and an interesting combination of "God Save the King" and "America" (The tune is the same, and the words don't matter; every true continental American knows how to sing both at once!), the guests were hurried to their train, which conveyed them, during the rest of the night, to Northport, B. C., and Grand Forks, Wash.

It may be observed here that the Institute party, like the Columbia river, paid no attention to that imaginary line known as the "international boundary." During the journey here described, that line was crossed ten times, in one direction or the other; but custom-house delays and formalities were practically eliminated by the careful pre-arrangements of Mr. Dwight, facilitated by the courtesy of both Governments.

Grand Forks.

Arriving at Grand Forks, Thursday morning, June 29th, the party was met by a reception committee, comprising Mayor Hammor and Messrs. W. T. Speir, G. M. Fripp and L A. Manley representing the citizens, Messrs. A. B. W. Hodges, A. L White, and other officers of the Granby Consol. Mining, Smelting & Power Co., together with a full delegation from the local press, and a number of ladies. The great smelting-works were at once inspected, under the guidance of Supt. Hodges, Assistant Supt. Williams and their staff. From the "Holiday Midwinter Number" of the *Phœnix Pioneer and Boundary Mining Journal* (January, 1905), the following notes concerning these works have been made:

The construction of the first two furnaces was begun in July, 1899, and the first ore was received in July, 1900. The first furnace started August 21, the second October 13, 1900, and additional furnaces were put in blast February 27 and March 17, 1902, November 5 and November 6, 1903; October 3, 1904, and June 20, 1905, making eight blast-furnaces now in operation, together with a reverberatory and a two-stand converter plant The present smelting-capacity is between 2,600 and 2,700 tons of ore, and the converting-capacity from 90 to 130 tons of matte, in 24 hours. Electric power is employed—about 1,100 h p being generated at the company's own power-house, on the north fork of the Kettle river, just below the smelter, and any necessary additional amount, up to 1,000 h.p., from the Cascade Water, Power and Light Co, which supplies at Cascade, about 12 miles from the smelter, a current of 2,000 volts, reduced by the step-down transformers at the smelter sub-station to 500 volts.

The quantities of ore treated in successive years, as shown in the following statement, were furnished by the company's Phœnix mines (with the exception of

occasional small shipments from other mines in the Boundary, Kootenai and Republic districts:

Ore Treated at the Granby Smelter at Grand Forks, B. C.

Year.	Tons.
1900,	62,387
1901,	230,828
1902,	312,340
1903,	401,921
1904 (estimated),	578,000
Total,	1,585,476

For the fiscal year ending June 30, 1905, the product was officially reported as: copper, 14,237,622 lb.; silver, 212,180 oz; and gold, 42,884 oz.

The ore of the Granby Company's mine, though running low in copper, is practically self-fluxing, and can therefore be directly smelted, while its contents in gold and silver contribute a considerable profit. These elements of commercial success have been utilized with great ability through a most impressive system of cheap transportation and handling by machinery, reducing the expense of manual labor. The automatic furnace-charger, designed by Supt. Hodges, is very ingenious and entirely successful. (A paper by Mr. Hodges, describing it, was read by title, for subsequent publication, at the Victoria meeting.)

PHŒNIX.

After luncheon at the offices of the smelting-works, the party proceeded in three coaches of the train to Phœnix, 30 miles from Grand Forks, by the Vancouver, Victoria and Eastern railroad.

Since the difference in elevation is more than 2,500 ft., the grades are necessarily heavy, and the line is tortuous. These facts alone would cause an experienced traveler to expect, in such a region, a picturesque journey; and these expectations were amply fulfilled, as the party was conveyed along the precipitous hillsides, up the valley of Fourth of July creek to Summit, and thence, high above Greenwood, to the head-waters of Eholt and Providence creeks, and so to the western end of the town of Phœnix. At the other end of town is the station of the Canadian Pacific branch. That company is said to have expended about $5,000,000 upon this and other branches in the region, chiefly for the purpose of making connection with the

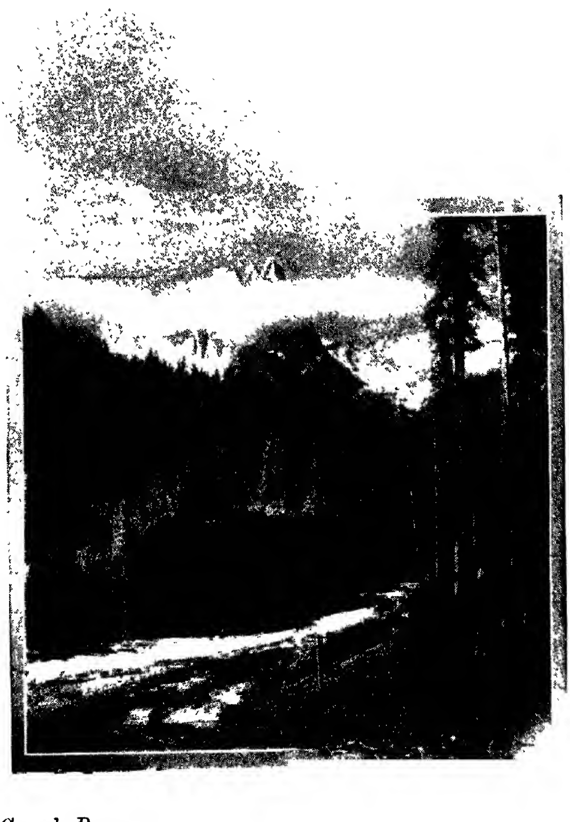
Granby mines and smelter. The 30 miles of the new Vancouver, Victoria and Eastern road from Grand Forks to Phœnix, belonging to the rival Great Northern system, cost about $1,000,000. Such liberal outlays not only indicate the great actual and prospective value of the industry and trade which they are intended to develop, and the far-seeing enterprise of those who take the risk involved, but also furnish, in their results, striking illustrations of a function of American railroads too often ignored or underrated by economists and legislators, who regard them only as common carriers—namely, the function of creating and increasing production, population and trade, which could not otherwise exist or grow.

At Phœnix, the party was hospitably received by Supt. O. B. Smith and the officials of the Granby Company's mines, who conducted their guests to various points of interest, such as the "glory-hole" of the Knob Hill mine, where the steam-shovel was at work, the big air-compressor, No. 1 Tunnel, etc., and afterwards to the company's office, where the ladies of Phœnix served refreshments; and beautiful and interesting souvenirs, in the way of photographs, illustrated descriptive publications, crystalline mineral specimens, etc., were generously distributed. The maps of the mine-workings were also exhibited, and intelligent explanations were freely given to all inquiring students of the nature and form of the ore-deposits.

Without attempting here a complete scientific account of these remarkable deposits, it may be said that they contain immense masses of sulphide ore, carrying a small percentage of copper, with values in gold and silver which become important when large quantities of ore are economically treated The weight of ore shipped by the company's mines during the year ending June 30, 1904, was (after deducting the moisture) 514,387 tons. A rough calculation, based upon the figures already quoted in connection with the smelter, indicates that this ore yields somewhat less than 1 5 per cent of copper, 30c. worth of silver, and $2 in gold, per ton It is self-evident that such an ore could not possibly be mined, transported and metallurgically treated with profit, except by a complete combination of engineering and metallurgical skill, mechanical systems of handling, etc , and thorough, systematic executive management and economical control, aided by exceptionally low rates of railroad-transportation. In other words, if the railroads had been by law forbidden (as they are now practically forbidden in some of our States) to give special encouragement to this enterprise, or if their rates had been made subject to the decisions of a government commission, capital would not have been risked in the building of expensive branches; the mines would not have been worked at all; and the smaller concerns which, in some cases within the United States, so bitterly and so effectively complain of "discriminations" in favor of large concerns, would not have been thus wronged, because

Avalanche Basin, near Bolton, Mont.

Pyramid Peak, Lake McDonald Country.



Mt. Index, Cascade Range, Washington.

they would never have existed. In the relative freedom left to individual enterprise by the Imperial and Provincial governments of Canada, and the consequent activity of the railway companies of the Dominion, lies a part of the explanation of the novel and startling phenomenon of the present unprecedented emigration from the United States into Canada.

FROM SPOKANE TO SEATTLE.

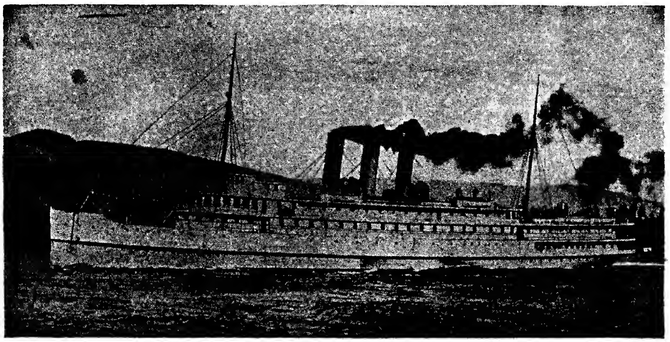
Returning to Spokane, the party proceeded to Seattle over the Great Northern railroad, the passage of which through the Cascade range occupied the whole of Friday, June 30th. Both

Crossing the Cascades on the Great Northern Railroad.

the engineering and the scenery of this section furnished surprise, as well as keen enjoyment, to all. With the exception of the Canadian Pacific, no one of the American transcontinental railroads can offer to its passengers, in this part of its route, such wonderful and fascinating views. Even the Central Pacific crossing of the Sierra, as it would be if the snowsheds were all removed, could scarcely claim scenic superiority; and as it *is*, must be adjudged to be hopelessly outside of comparison. The loops; the climbing, winding grades; the tunnels (through one of which the train goes into the heart of

a solid mountain, turns about within it, and emerges not far from where it entered, only moving in the opposite direction); the lofty summits; the thickly forested cañons; the long, hazy vistas; the sudden glimpses and panoramas; the dizzy precipices and leaping cascades—following one another in swift succession—combined to create a bewildering and exciting day's experience.

Seattle was reached at too late an hour in the evening of Friday, June 30th, to permit any formal entertainment of the party; but a number of the citizens were awaiting its arrival; and during the brief available interval, before the steamer left for Victoria, many of the excursionists were enabled to see something of the city. Those who had previously visited



The "Princess Victoria."

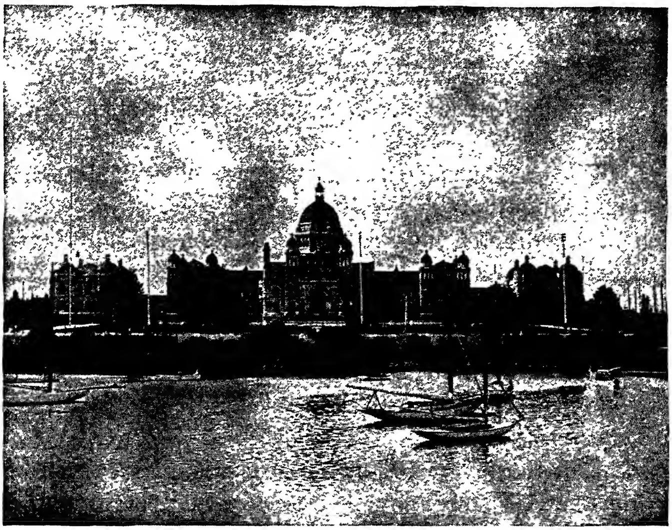
Seattle could not fail to realize the rapidity of its recent growth and progress.

Victoria.

The beautiful and luxurious steamer "*Princess Victoria*" conveyed the party to Victoria, which was reached at 7 a.m. on Saturday, July 1st.

The forenoon was spent in driving or walking through this attractive city and its suburbs. It may be remarked here that, throughout the period of their stay, the members and guests of the Institute were the recipients of innumerable social attentions from the Local Committee, leading citizens and ladies of Victoria—tally-ho coaching-parties, carriage-drives for smaller companies, afternoon teas, lawn-parties, etc. These were in-

terpolated, at every possible opportunity, between the technical sessions of the meeting and the more formal general excursions and entertainments, and were so numerous and so informal as to escape particular record, except in the memories of those who enjoyed them. No form of hospitality could have been more delightful, or better calculated to produce an indelible impression of the bright city, with its shady parks; its stately or picturesque homes; its verdant lawns and gardens fairly smothered with blossoms; its balmy and refreshing summer air; its endless variety of scenic views, lovely or grand, culminating



Parliament Buildings, Victoria, B. C.

in the unrivalled panorama of the snowy Olympic range in Washington, seen on the southern horizon, beyond the Straits of Juan de Fuca; and, above all, its genial and generous inhabitants.

The visit of a small party to the Vancouver Portland Cement Company's works at Tod inlet deserves special mention, on account of its professional interest.

Saturday evening, a public reception, under the auspices of the Government of British Columbia, was given in the Legislative Hall of the Parliament Buildings, where the venerable

and beloved Sir Henri Joly de Lotbinière, Lieutenant-Governor of the Province, assisted by Hon. Richard McBride, premier and minister of mines; Hon. F. J. Fulton, provincial secretary; Hon. R. F. Green, commissioner of lands and works, and Hon. R. G. Tatlow, minister of finance; Hon. A. E. Smith, United States consul; His Worship the Mayor of Victoria (Mr. G. H. Barnard), Mr. S. J. Pitts, president of the Victoria Board of Trade; Col. Prior, Major Dupont, Hon. E. Dewdney, Hon. C. E. Pooley, Canon Beanlands and many other distinguished citizens, with a goodly array of charming ladies, extended a graceful and cordial welcome. A noteworthy feature of the decorations of the building was the marvellous display of roses arranged in the *foyer* before the Legislative Hall. These were afterwards bestowed upon the ladies of the visiting party. The corridors, galleries and museums of the building afforded ample room, not only for the suitable disposition of orchestra, refreshment-tables, etc., but also for most agreeable private saunterings and colloquies.

The illustration of the Provincial Parliament Buildings, accompanying this narrative, conveys a general notion of their admirable proportions, style and surroundings. While the effect of mass and stateliness has been retained, that of monotony has been avoided, by separating the buildings at either end, and connecting them with the central building by *porte-cochères* and galleries.

Mr. F. M. Rattenbury, the architect, was, at the time when his design was selected as the result of an open competition, young and comparatively unknown. His work fully vindicates the decision of the judges in his favor. The astonishing fact that the total cost of these buildings, including their interior fittings and furniture, was but $1,000,000, indicates not only honesty, economy and loyalty on the part of everybody concerned, but also the perfection and thoroughness of the plans and specifications, and the consequent avoidance of those afterthoughts and oversights, requiring changes of detail, which almost always enhance the estimated expense of such undertakings.

The Archipelago.

Monday, July 3d, was devoted to an excursion, given by the Victoria Board of Trade, on the steamer "*Charmer*," through

the magnificent archipelago lying east of Vancouver Island, and including, among other places of historic interest, the island of San Juan, so long in dispute between the United States and Canada, but now belonging to the former country. A curious result of this political change was seen from the deck of the steamer, namely, cement-works upon the island, the product of which, being American, enjoys in the important market of the Sandwich Islands a great commercial advantage over the Canadian works which formerly possessed that market.

Professional considerations and reflections, however, played little part in the experiences of the day, which was given up to sentiment and social pleasure, inspired by glorious weather, superb scenery, complete physical comfort and the best of company. The white crests of the Olympics, already familiar, yet never to be seen too often, bounded the view for a part of the time, going and coming; and, after turning northward away from them, the steamer glided among the wooded islands and over the clear green waters of the beautiful archipelago. Similar scenery on a grander scale awaited the travelers at later stages of their long journey from Victoria up the coast; but that unknown future could not impair the admiration with which this foretaste of its glories was appreciated.

The Tyee Mines and Smelter.

On Tuesday, July 4th, the party were the guests of the Tyee Copper Co., the general manager of which, Mr. Clermont Livingston, had arranged a double excursion, to the company's mine and smelting-works, respectively. A special train on the Esquimault and Nanaimo railway conveyed all to Duncan's, 40 miles from Vancouver, where those visiting the mine took carriages for a drive of 11 miles to Mt. Sicker, while the rest proceeded 20 miles further by rail to the Tyee smelter at Ladysmith. The line from Victoria to Duncan's follows for some distance the precipitous coast of Vancouver Island, commanding a superb view from above of the sounds, inlets and islands among which the happy voyage of the day before had been made.

The road from Duncan's to the mine passes for 5 miles through cleared land with numerous small farms, and then ascends for 6 miles through almost unbroken forest. Frequent

wayside springs and streams, and a great variety of flowers in bloom, tempted the tourists to walk and to linger; but they reached in good time the mining camp, the buildings of which had been decorated in their honor with flags and evergreens. A number of zealous mining engineers and geologists, driving through with special speed, had time to see a good deal of the underground workings. The rest were contented with a briefer inspection.

The following notes concerning this enterprise are taken from the *British Columbia Mining Record*, July, 1905, published at Victoria:

"The Tyee, Lenora, and other mineral claims on Mt. Sicker, were staked in April, 1897. After some prospecting work had been done, Mr. Livingston, seeing the promise the Tyee gave of proving a good property, bought an interest in it. Exploratory work was then done, with results that encouraged Mr. Livingston to proceed to London, where he succeeded in interesting capital in it.

At first a company was formed with 15,000 shares and £5,000 working capital, and a shaft was sunk 200 feet. In 1900 the shares of the Tyee Company were increased so that there were 120,000 shares. The company issued 100,000 shares and had £20,000 working capital. Mr. E. C. Musgrave, who is superintendent of the mine, joined the company in 1900, and next year he located a big ore-body, which has since been worked with good results. It is estimated that before this ore-body shall have been worked out it will have produced from 200,000 to 300,000 tons of commercial ore. Fresh stock was issued in October, 1901, increasing the company's shares to 180,000 with £50,000 working capital. Then the more extensive development of the Tyee mine was entered upon An aerial tramway was built 3.5 miles down to the E & N. railway; a hoisting-engine and two cages, five boilers, air-compressor, steam-pumps and other machinery were installed, contiguous claims were secured, timber-limits and land were obtained from the Esquimalt & Nanaimo railway, and the smelter was built at Ladysmith. This smelter has since treated 125,000 tons of ore from the mine.

Up to the end of April, 1905, £112,000 in profits for the last two years' work had been sent to the directorate in London, which not only paid a dividend of 20 per cent., but also placed a substantial amount to credit of a reserve-fund, and this, too, with considerable exploratory and development-work proceeding down to the 800-ft. level, at which depth cross-cutting was lately commenced, and prospecting with the diamond drill is being done."

A bountiful collation was served in the saw-mill (near the mine-shaft), which had been transformed by graceful adornment into a festal bower, where branches and banners concealed the rough walls and the dismantled saw-frame. For the zeal and taste exhibited in this rustic decoration, the ladies of the camp deserved and received much praise.

In honor of the day, a facsimile of the American Declaration of Independence, draped in the Union Jack and the Stars and

Stripes, hung behind the seat of Mr. Livingston, himself a descendant of one of the immortal "Signers," who presided and announced the first toast, to "King Edward and President Roosevelt." To this sentiment a suitable response was made by Hon. A. E. Smith, U. S. consul at Victoria; and a toast to the American Institute of Mining Engineers was acknowledged by the Secretary; after which Mr. E. V. d'Invilliers proposed the health of Mr. Livingston, Mr. E. C. Musgrave, the Superintendent of the mine, and their associates, which was drunk with cheers. The party then returned to their wagons, and swiftly descended the mountain to the station at Somenos, where the train, coming back from Ladysmith with the other excursion party, was boarded for the common return to Victoria.

The following account of the visit to the smelter (in which the writer did not take part) is condensed from the *British Columbia Mining Record* for July, 1905:

At the Ladysmith station, the party was met by Mr Thomas Kiddie, manager of the smelter, and his assistant, Mr W J Watson, and conducted through the general offices of the company, the assay-office and the works These works, situated between the Esquimalt & Nanaimo railway and Oyster Bay, have a water-frontage of about 3,000 ft long, besides ample room for slag-dumps for years. The ground has been laid off in terraces, permitting a gravity-system throughout, and the works were built from the designs of the manager, whose son, Mr. John Kiddie, C. E, had charge of construction, with Mr. George Williams, now mechanical engineer at the British Columbia Copper Company's smelter at Greenwood in the Boundary district. Mr. W. J. Watson is assistant superintendent and Mr. H. Collinson chief chemist.

The plant now has a capacity of 250 tons daily; but provision has been made for enlargement to 600 tons, and room left for a bessemerizing plant whenever these additions shall be deemed desirable.

The ore from the Tyee mine (which constitutes by far the larger part of that treated here, the remainder being custom ores), is brought from the lower terminal of the company's aerial tramway near Somenos, 17 m. from the smelter, in bottom-dumping 30-ton railway-cars, the proportion to be smelted raw going to receiving-bins immediately behind the furnace-house, and that to be roasted to bins above the roast-yard at the highest level of the smelter-site. A spur from the railway runs, on a rising grade, to the top of the roast-yard receiving-bins, of which there are 16, having a total storage-capacity of about 1,600 tons of crushed ore.

The ore falls from the railway-cars upon fixed screens, set in the bins at an angle of about 40°, from which the fine ore ($\frac{3}{8}$-in. size and less) falls into a separate compartment, in the center of each bin. Through the bottom-discharge-doors of the bins the ore is drawn off into ore-cars running on tram tracks, the roughs going to the roast piles and the fines to the brick-house, to be made into bricks.

The handling of ores in the roast-yard is facilitated by an ingenious system of longitudinal permanent trestles through the yard, 60 ft. apart, and movable tramway-bridges, traveling on wheels, and spanning this interval.

The roast-piles are 50 ft. long by 40 ft wide and 8 ft. high, and contain about 350 tons of ore each. The object in not building them higher is to shorten the time required for roasting and, as well, the period during which the burnt ore shall necessarily be exposed to rain and consequent leaching, this latter being an important consideration where the rainfall is considerable The ore is piled on a layer of about 12 in of cordwood, each pile requiring about eight cords of wood The period ordinarily occupied in burning these piles of ore is about three weeks.

The bricks of fines are roasted with the screened ores The process of making the fines into bricks is as simple as that of ordinary brick-making The plant consists of two 1-h p pug-mills and a bottom-heated drying-floor, so arranged as to equalize the heating over the whole floor space. The building housing the former is 60 by 30 ft , and that covering the latter 140 by 30 feet. The capacity of this plant is 8,000 bricks, equal to 28 tons of ore, per day. The ore-bricks are treated like the other ore in the roast-heaps After burning, they are hard and porous, and highly suitable for smelting in the blast-furnace. The oxidation of the zinc, copper and iron in the bricks is remarkably complete, average samples of large piles of burnt bricks giving from 1 5 to 2 5 per cent of sulphur (as sulphides), as against 7 per cent in the ordinary burnt ore This process does away entirely with any necessity that might otherwise exist for building and operating mechanical roasting-furnaces and the subsequent briquetting of the roasted material. The roasted bricks are also an improvement on the ordinary briquettes, which at best are tender and very liable to make fines in the furnace, thus retarding its work These bricks, on the other hand, stand rough handling and usage and are a valuable addition to the furnace-charge of ordinary burnt ore

The ore from the Tyee mine has proved to be comparatively free-burning, and occasions little trouble by its sintering in the roast-heaps The average of 7 per cent of sulphur in the roasted ore does not include the sulphur of the barium sulphate, which the roasting does not affect

The water-jacketed furnace, 42 by 120 in at the tuyere-line, has 14 tuyeres of about 6 in diameter There are two water-jacketed fore-hearths The slag is granulated by water A brick dust-flue, 8 ft. by 11 ft by 165 ft long, leads to an iron smoke-stack 7 ft. diameter and 90 ft high. The engine and boiler-house is 60 ft. distant from the smelter-building An 80-h p return tubular boiler supplies steam to a 14 by 36-in Reynolds-Corliss engine, which drives a No 7 Connersville blower and, by means of a rope-drive, operates the matte-crushers and elevators in the smelter A separate 17-h p. engine runs a 200-light dynamo for lighting the works and offices.

A new hot-blast system, utilizing the waste heat of the blast-furnace, which had been in operation but a few days, was reported, as compared with the former cold-blast practice, to have reduced already the coke-consumption, besides permitting a larger proportion of raw ore in the charge, and producing a cleaner slag.

The process of matte-smelting followed at these works was the subject of a paper by Mr. Kiddie, presented in oral abstract at the Victoria meeting, and to be hereafter published. From the analyses exhibited, metallurgists could easily infer that the problem to be solved was a peculiarly difficult one, namely, the

smelting of an ore containing, with 4.08 per cent. of copper, and 10.49 of iron, 37.63 of barium sulphate, 7.36 of zinc, and 13.48 of silica; while the success of the metallurgical solution of this problem was evident in the production of a slag containing only 0.41 per cent. of copper, 0.14 (out of an original 2.67) oz. of silver, and a trace (out of 0.131 oz.) of gold per ton.

After inspecting the works, the visitors were introduced to Mrs. Kiddie, in the grounds adjoining the manager's house, where, in a gaily decorated marquee on the lawn, a bountiful luncheon was served. Mr. Kiddie proposed the health of "The King and President Roosevelt," speaking in this connection of the death of ex-Secretary Hay, which had been deeply felt by the British as well as the Americans Captain R. W. Hunt responded in a felicitous speech. The Mayor of Ladysmith, Mr. J. W. Coburn, then extended a civic welcome to the visitors, expressing the hope that the trip of this party of distinguished mining men might not be without benefit, both to themselves and to the sections they visited. After an appropriate song, "Ten Thousand Miles Away," by Gen. Chas. F. Roe, Maj. Chas. E. Lydecker proposed a toast to the ladies. Col. E. G. Prior spoke eloquently of American and Canadian institutions, and the good feeling between Canada and the United States. Speeches and songs by Col. E. G. Prior and Mr. W. F. Robertson, on the part of the hosts, and Gen. Chas. F. Roe, Maj. C. E. Lydecker, and Dr. Joseph Struthers, on the part of the guests, were followed by the enthusiastic reception of a toast in honor of Manager Kiddie and the Tyee Copper Co. At the latest practicable moment, the festive party reluctantly resumed the special train for Victoria.

After the session of Wednesday forenoon, July 5th, the Provincial Mineral Museum, in a separate house near the Parliament Building, was visited under the guidance of Mr. W. J. Sutton. One of the most interesting exhibits in the museum was an elaborate glass model of the Highland mine, at Ainsworth, in the West Kootenai district, contributed by Mr. Norman Carmichael, the manager.

After the final session of Wednesday afternoon, the unbroken series of delightful experiences vouchsafed to the representatives of the Institute in Victoria was fitly crowned by a brilliant reception, given on Wednesday evening at the Government

House by Lieut.-Gov. Sir Henri Joly de Lotbinière, at which the leading members of political and social circles in Victoria, including many charming ladies (already acquainted, through their own cordial hospitality, with the ladies of the visiting party), co-operated with the genial Lieut.-Governor to signalize this cordial farewell. It must be said, however, that the genial Sir Henri scarcely needed any re-inforcement. His impartial, universal gallantry, of the graceful, antique, courtly type, captured all hearts, of both sexes; and it was not surprising to hear that both the political parties of the Province had joined in the petition that, at the approaching close of his term, he should be reappointed to his high office.* Certainly no one could more winningly represent the Province in the reception of guests from abroad.

The Victoria Government House, designed by the young architect of the Parliament Buildings, to whom reference has been made already, though not an immensely great and expensive palace, is a work of exceptional genius, perfectly adapted to its site and purpose; and its spacious halls, saloons and corridors, together with its magnificent outlook, over the sparkling waters of the Straits to the white summits of the Olympic range, made it a fitting climax and summary, for the guests of this occasion, of their memorable visit to Victoria.

VANCOUVER.

After midnight, the steamer "*Princess Victoria*" conveyed the party to Vancouver, which was reached on Thursday morning, July 6th.

The following outline of the proceedings of the day is condensed from the *British Columbia Mining Record* for July, 1905:

The joint reception committee of the City Council, Board of Trade, Tourist Association and Mining Association met the party at the wharf and extended to them the freedom of the city. At 9 30 two prettily-decorated cars, which had been provided by the British Columbia Electric Railway Co., were boarded, and while some of the members visited industrial establishments, others were taken about the city over the various car-routes The Pacific Coast Lumber Company's saw-mill on Coal Harbor, the Vancouver Engineering Works, and the large ware-

* The chief executive officer of the Dominion of Canada is the Governor General. The highest executive title in a Province of the Dominion is "Lieutenant Governor," and, in a Territory, not yet organized into a Province, "Commissioner."

houses of the wholesale hardware firm of Wood, Vallance & Leggat, were inspected.

Shortly after noon all the party gathered at the Hotel Vancouver, where they were ~~met by~~ many of the principal residents of the city, and after an informal reception luncheon was served. Some 200 in all were seated at the tables, many ladies and a large number of prominent citizens being present.

Mr. Colin F. Jackson, President of the Vancouver branch of the Provincial Mining Association, presided, and after a brief address, assuring the visitors of the hearty welcome of Vancouver, offered toasts to "The King and the President of the United States," which were enthusiastically received, "God Save the King" being sung in one instance and "The Star Spangled Banner" in the other.

His Worship, Mayor F. Buscombe, proposed the health of the American Institute of Mining Engineers, and expressed the belief that this visit would mark an epoch in the history of mineral development in British Columbia.

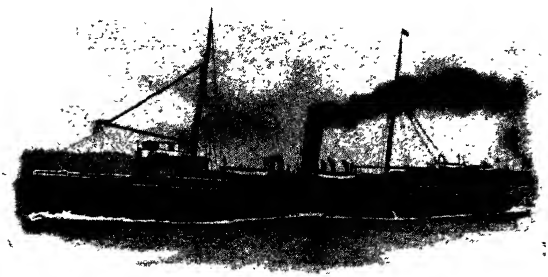
Mr. R. P. McLennan, of Dawson, Yukon Territory, here extended the invitation of that city. In the course of his remarks Mr. McLennan observed that ever since Sunday-school days it had no doubt been the dream of all to enter the golden city. Now, the engineers and their families were about to have their dreams realized, by their pilgrimage to a town whose streets were paved with gold—"fine gold" in the very soil—while, just now, there was "no night there"!

After a response by the Secretary of the Institute to these cordial addresses, guests and hosts were distributed in carriages for a drive through Stanley Park, one of the most beautiful pleasure-grounds on the Canadian coast. This park occupies the whole of a large island, partially covered with a forest of fine trees, some of which are of extraordinary size. A promontory at the end of the island, which forms one side of the narrows through which ocean-vessels come and go, commands a magnificent prospect of the extensive harbor, the mountain range beyond, and, in the farthest distance, the white dome of Mt. Baker pencilled upon the sky.

The Coast.

At 1.30 a.m., Friday, July 7th, the steamer "*Princess May*," began its voyage along the coast to Skagway, a distance, by the route taken, of about 900 miles. The voyage was made by the inner channel, which is almost continuously protected from the swell of the Pacific by Vancouver, Queen Charlotte, Prince of Wales, and other islands. During the two brief periods of exposure to the open ocean (in crossing Queen Charlotte Sound and the Dixon entrance, opposite Port Simpson) the waves were so quiet that the comfort of the travelers was not disturbed.

At this point it is appropriate to emphasize the extraordinary good fortune which lent to the long journey, from New York to the Yukon and back, its last touch of perfect enjoyment, in the practically unbroken prevalence of clear weather. The importance of this condition to tourists visiting Alaska is notorious. The great risk of that undertaking is, that the magnificent scenery may be obscured by smoke, rain or fog. Thirty-seven years ago, on his first visit to Oregon and Washington, the writer experienced such a disappointment, riding through burning forests, the smoke of which dimmed the air for hundreds of miles, so that Shasta, Hood, Rainier, Adams, St. Helen's, and the splendid banks of the lower Columbia, were invisible, even from their immediate vicinity. There was much reason



The "Princess May."

to fear a similar disappointment for the Institute excursion of this year. For some weeks, the newspapers had been reporting extensive forest-fires along the northern Pacific coast, which nothing but heavy rains could extinguish, and the smoke of which dismally enveloped sea and land. During the Victoria meeting, the needed rains were reported to be falling; but their first effect was to make more smoke, and to add mist and fog to the atmosphere. Mr. McInnes, the new Commissioner of the Yukon Territory, who hastened his journey to Dawson, arriving there about 10 days in advance of the Institute party, in order to get through with his own inauguration in office, and prepare for the reception of the expected guests, encountered these unhappy conditions; and his wife, who sailed from Victoria only three or four days ahead of the Institute party, for the purpose of assisting him in his official hospitality, was

scarcely able to catch, through the fogs and rains, a glimpse of the land. Yet when the "*Princess May*" left Vancouver, smoke, rain, fog and storm had completed their work and departed, leaving a new heaven and a new earth, washed clean of every stain, and visible not only in aggregate majesty of mass and outline exhibited by peaks, precipices and glaciers, or inlets, bays and sounds, but also in every delicate detail of bower, glade, brook, tree or flowering bush.

For about 400 miles north of Vancouver, the heavy timber, characteristic of southern British Columbia, continues. Further north, the trees are small.

The comparison between this scenery and that of Norway is inevitable. But some of the party who had coasted that country declared vernacularly that, compared with this, Norway was "not in it;" and others retorted that if Norway were in it, Norway would be lost beyond identification in the overwhelming extent of this grandeur. This opinion is certainly not exaggerated, if to what was traversed by the Institute party be added those portions of the Alaskan coast, west of Skagway, which it did not see—notably Prince William Sound, surrounded by the most impressive glaciers in the world.

The whole voyage presented an ever-changing, never-wearying succession of fiords, bays, sounds and inlets, bounded by steep heights, up which the forests climbed, in gradually thinning ranks, until, beyond the straggling van-guard of trees, rose the stark rocky heights "above timber-line." But all the elements of beauty and sublimity were concentrated in the famous "Lynn canal," between Juneau and Skagway—a narrow passage, bordered on both sides by mountains from 3,000 to 5,000 ft. high, bearing great glaciers and banks of perennial snow, from the edges of which innumerable cascades slide and leap to the shore, threading the woods like silver ribbons, and visible sometimes only in disconnected parts, as if "stitching" the green carpet of foliage, and sometimes (as the ship reaches a new view-point) through their whole dizzy length of 3,000 or 3,500 feet. Once, a dozen glaciers, and nearly as many foaming cascades, were more or less fully visible at the same time; and there was not an hour without some new challenge to ecstatic, speechless admiration.

Brief stoppages were made on July 8th at Port Simpson, B. C.,

and Ketchikan, Alaska. Port Simpson is the most northern point of the coast belonging, under the recent boundary-settlement, to Canada; and is reported to have been selected as the western terminus of the new Grand Trunk Pacific road. It was hard to realize that, back of the mountains behind it, lay an agricultural region of unsurpassed productiveness. Yet this appears to have been proved beyond doubt, adding a new chap-

Lynn Canal, Alaska.

ter of surprise to the history of the development of the Northwest.

Many of us, not yet consciously very old, remember how Jay Cooke's enthusiastic prophecies concerning the country traversed by the Northern Pacific railroad were ridiculed, and how his diagrams of northward-sweeping isothermal curves of climate were humorously characterized as indicating "Jay Cooke's banana-belt," while Proctor Knott's famous ironical eulogy of Duluth, "the zenith city of the unsalted seas," was accepted as covering with clever burlesque a serious and weighty skepticism. But that period is long past; Duluth proudly wears in earnest the title conferred in jest; and the country developed

by the Northern Pacific has vindicated the once discredited prophecy.

Then came the Great Northern, upon a parallel route higher in geographical latitude; and this, many of us thought, was surely a foolish venture. But none of us would say that now.

The Canadian Pacific, however, we could safely characterize as an enterprise justified only by Canadian pride and governmental policy, and not at all by commercial reasons. If any vestige of this wise skepticism still remained among the members of the Institute party, it was forever dissipated by the unmistakable evidences of business, even to the point of congestion, along that railroad.

Now comes the transcontinental extension of the Grand Trunk, still further north, and expected to pay for itself without governmental subsidy, through the immense agricultural resources of the new region it will open.

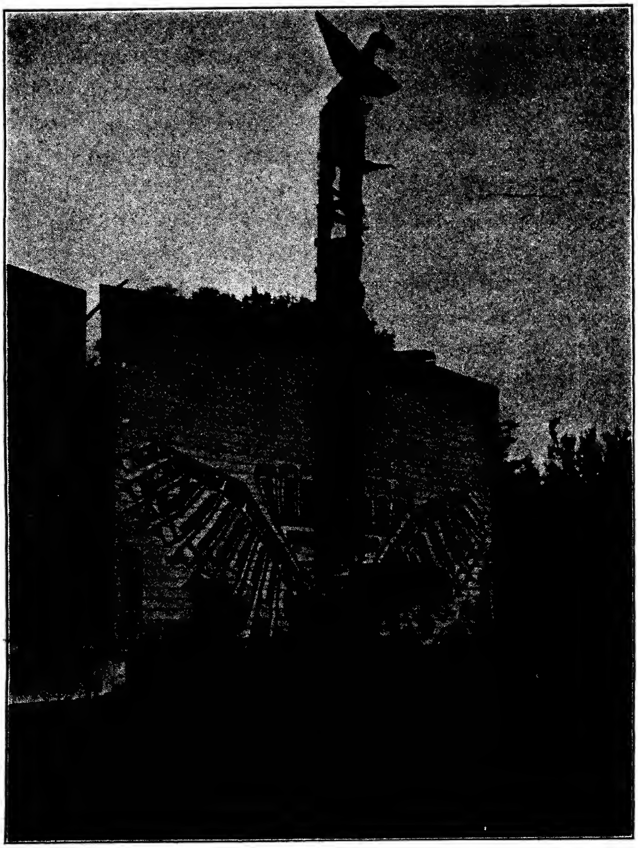
And finally, we are told by intelligent students of the Continent that there is still room to the north, and within the area of productive agriculture (especially the cultivation of wheat) for one, or even two, additional parallel lines of railway!

At present, Port Simpson is simply an Indian village; and the party found it almost deserted—the inhabitants being absent as temporary employees of the salmon-canneries, catching and dressing fish.

Ketchikan was reached late at night; but the citizens were awake and ready to welcome the party, many of the members of which landed, and inspected with interest not only the quaint town itself (largely built over the water and supported on piles) but also a collection of gold-, silver-, lead- and copper-ores, collected from Prince of Wales island and other places in the vicinity. The numerous promising prospects of mineral value all along the coast indicate resources which certainly deserve early attention and development, especially in view of the cheap water-transportation which gives them a valuable and immediate advantage.

At Port Simpson and Ketchikan, and at many villages along the coast, seen from the deck of the steamer, the curious Indian totem-poles were inspected with interest. (The illustration on page lxxxx is a photographic view of a curious totem pole in the front of a house at Alert Bay, B. C., which was visited on

the return trip down the Coast. The lower half of the bill at the bottom is hinged at the base, and has wooden steps on the inner side. By letting the front of the bill drop to the ground, a stairway is furnished for entrance into the house. The lower part of the doorway is seen below the base of the bill.)



Totem Pole at Alert Bay, British Columbia.

Numerous porpoises and whales were observed, disporting themselves in the clear, still water. On two occasions a fight between a whale and a "thrasher" shark was in progress as the steamer passed; and it often happened that a whale leaped wholly out of the water. To complete at once the chapter of natural history, it may be added here that afterwards, on the

Yukon, a lynx was encountered, swimming to the mainland from one of the islands, and later a bear was discovered clambering up a steep bushy bluff, but a few yards from the "*White Horse.*"

On the afternoon of July 9th, the party arrived at the famous Treadwell mine on Douglas Island, opposite Juneau, where the mine and stamp-mills of the company were inspected.

In view of the complete account of the geology, ore-deposits and mining and metallurgical methods of this mine, contained in the two recent and exhaustive papers of Messrs. Kinzie and Spencer* no further description need be given here.

A considerable number of the pilgrims crossed from Douglas Island by ferry to Juneau, in which thriving town they spent a pleasant hour.

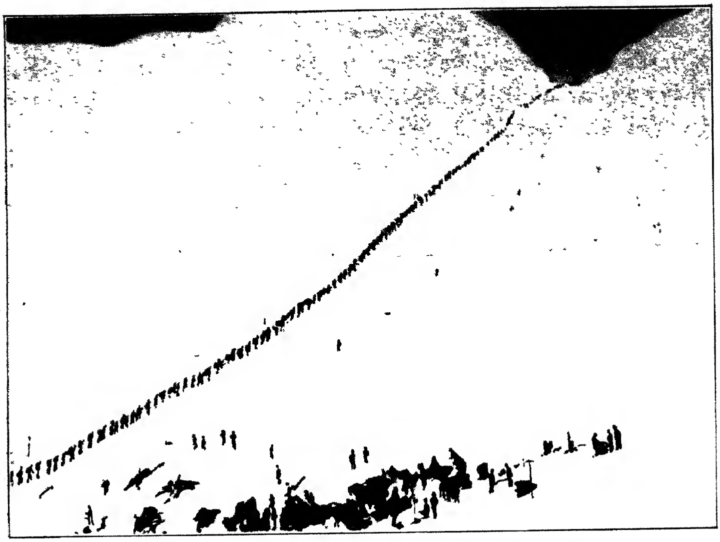
Between Vancouver and Dawson, the same route was taken (with some interesting minor variations and stoppages) both going and coming. But a special excursion has the great advantage of following its own schedule; and this had been skillfully utilized by Mr. Dwight, so that interesting regions were traversed, if in one direction by night, then in the other direction by day—a benefit not always conferred by the regular time-tables, and conspicuously illustrated by the trip through the sublime scenery of the Lynn canal. It must be confessed, however, that in these high latitudes, the night was neither long nor dark, and people sat up late without knowing it.

The White Pass.

Skagway was reached early in the morning of Monday, July 10th. This small but busy town, crowded into the mouth of the cañon leading to the White pass, and surrounded on all sides by precipitous mountains (from one of which the great Skagway glacier looks down upon it across the quiet waters of the bay) is the western terminus of the famous railroad over the White pass to the upper Yukon. Delegates from White Horse, the other terminus, met the party here, and superintended its transfer to a special train. The White Pass and Yukon railway from Skagway to White Horse (112 miles) traverses for

* The Treadwell Group of Mines, Douglas Island, Alaska, by Robert A. Kinzie, Asst. Supt., *Trans.*, xxxiv., 334; and The Geology of the Treadwell Ore-Deposits, Douglas Island, Alaska, by Arthur C. Spencer, *Trans.*, xxxv., 473.

the first 40 miles the White pass, tragically famous as one of the two passes (the Chilcoot being the other) where thousands



Procession of Adventurers Crossing Chilcoot Pass in 1898.

of adventurers perished in the endeavor to reach the new Eldorado of the Klondike. The cañon is narrow and precipitous and the steep railway-grade has been cut far above the old trail, in the granite, crossing at one point, by means of a steel cantilever bridge, a lateral ravine, through which a tumultuous cataract plunges to join the main stream. Still higher are the snowy summits and glaciers. The sublimity of these surroundings places this line among the foremost "scenic railways" of the world, and disposes the tourist to regard its construction as a great feat of engineering. But, in fact, to the eye of the engineer, the work appears to have pre-

Approaching the Tunnel.

sented no great difficulties, apart from its cost. For it involved simply the cutting of so much rock from a solid mass which would not cleave or slide, the building of a few culverts and retaining walls, and one bridge. Once done, it was good forever; and its maintenance is a matter of trifling cost. The great expense of keeping the line open in the winter (which requires the continuous use of a large number of rotary snow-ploughs) belongs to the summit-plateau, where snow lies deep, and not to the precipitous sides of the cañon, where snow can scarcely accumulate at all. Compared with railways in less imposing surroundings, which cross mountain-sides having what has been aptly called "finger-structure" (*i.e.*, frequently alternating ribs and ravines), necessitating innumerable tunnels and "fills" or bridges, and liable to slides of loose rock, the White pass road must be confessed to be "easy." But engineers are human; and the engineers of this party were not less ready than the rest to acknowledge the grandeur of the passage.

Hanging Rocks at Clifton.

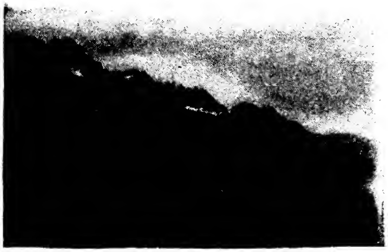
It was hard to realize that this rugged region, now so swiftly and comfortably traversed, had been less than ten years ago the scene of such terrible suffering and mortality. Neither the severity of the winter climate nor the difficulties of the topography adequately explain that awful story. The true explanation, given to us by several persons who had, without special suffering, made the crossing at that very period, was the incredible ignorance, inexperience, unpreparedness and reckless haste of the crazy adventurers themselves. Such frantic fools could have starved or frozen anywhere.

White Horse.

Arriving at White Horse, the party was divided into three parts, two of which were conveyed in wagons to visit respectively the Copper King and the Arctic Chief copper-mines, while the third (including most of the ladies) was similarly

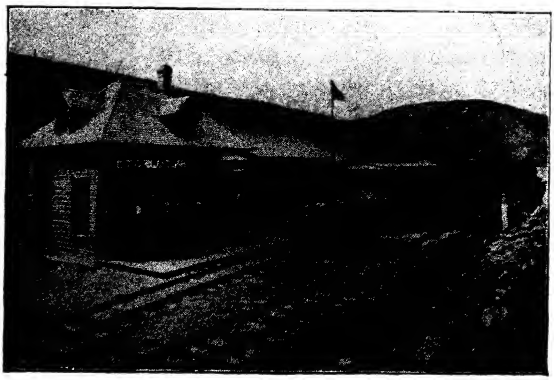
taken to the head of White Horse cañon, where they were enabled to witness (as spectators, or, if they desired, as passengers) the passage of a lumber-barge through the famous rapids.

The auriferous copper-belt of White Horse, extending, as far as now known, about 16 miles in a curve around the town, presents a considerable number of promising "prospects" of high-grade ore, some of which will doubtless be successfully developed in the near future, especially if (as seems to be beyond doubt) the present progressive world-demand for copper shall continue. The reported offer of a rate of $5 per ton for ore in sacks, or $6 in bulk from White Horse to the Tyee Company's smelter at Ladysmith, on Vancouver island (a distance of 112 miles by rail and 900 miles by water), leaves some margin of profit on the mining and shipment of rich copper-ores; and this operation may be expected to promote the development of mining on a larger scale, and the realization of economies in all the departments (including transportation) which will make ores of lower grade profitable.



The Saw-Tooth Mountains.

Up to the present time, about 500 locations have been made in the belt, and about 200 kept valid by annual work. The greatest depth of workings is about 189 ft., and the total shipments of ore have been about 1,000 tons, ranging in value (for 100-ton lots) from $16 per ton for ore not sorted, to 46.64 per cent. of copper and 11 oz. silver and $2.58 gold per ton. One lot is reported to have yielded a net profit, over cost of freight and treatment, of $32 per ton.



The Summit of White Pass.

The prevailing mineral in these ores, so far, is bornite, carrying gold and silver. Since this mineral is generally recognized as a secondary product, not likely to continue to great depth, the nature and value of the deeper parts of the

deposits can only be determined by development, for which, fortunately, the rich bornite of the upper levels may furnish the means.

Besides these copper-deposits, there is, within 20 m. of the town, a considerable area, within which several workable seams of coal, from 16 to 18 ft. thick, are reported to exist. This coal is said to be "an anthracite in character," though the analysis given, showing only 78 per cent. of fixed carbon, scarcely warrants this classification. Other deposits, further away, are said to yield good coking coal.

Two or three weeks before the visit of the Institute party, the business part of White Horse had been almost totally destroyed by fire; and the visitors consequently arrived in the midst of the manifold and intense activity of rebuilding the town. But this did not seem to interfere in the least with the plans of municipal hospitality, which included, besides the pleasant drives already mentioned, the distribution of dainty souvenirs, printed upon silk, and setting forth the attractions and resources of White Horse, and, finally, a midnight farewell banquet, given in the club-house of the "Arctic Brotherhood," which had fortunately been spared by the recent conflagration. At this banquet the "local talent" of White Horse was most agreeably exhibited in speech and song; and Mr. Robert Lowe, who presided, presented the following address, beautifully printed upon rose-colored silk, and encased in a box, decorated with paintings of Arctic scenes —mining, traveling with dog-teams, etc.

The Cantilever Bridge.

TO THE AMERICAN INSTITUTE OF MINING ENGINEERS.

GENTLEMEN :—

The Citizens of White Horse extend to you, the representatives of the American Institute of Mining Engineers, their most hearty welcome, not only to their town, the Gateway of the Yukon, but to the Territory as a whole, on this, the first visit of your influential Association to this Great Northland, which has been in the past and will in the future undoubtedly be an important factor in the industrial and economic life of the Dominion of Canada.

Our townspeople are exceedingly gratified that your itinerary permits a short stay in the White Horse district, but regret, considering the various and vast mineral resources and great possibilities of the district, that more time is not afforded you to thoroughly acquaint yourselves with its resourcefulness.

We sincerely trust that your short visit may result in material benefit to yourselves as well as advantage to us.

To the ladies of your party we extend the freedom of our town, of our homes and the kindliest feeling of our hearts, and hope that they will carry away with them pleasant memories of our town and its people.

For the Citizens of White Horse.

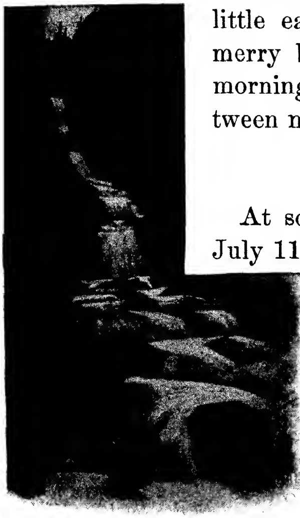
ROBERT LOWE,
Chairman.

WHITE HORSE, July, 1905.

During the evening a brief shower, followed by a magnificent, complete rainbow at 9.30 p.m., emphasized to the pilgrims the high latitude they had already reached, as did, likewise, the fact that the succeeding sunset-glow, a very little west of north, had scarcely faded before the sunrise glow, a little east of north, began. Of course, the merry banqueters did not come home till morning, and could not see any difference between morning and any other time of night!

ON THE YUKON.

At some small hour of Tuesday morning, July 11th, the party, comfortably embarked upon the two sister stern-wheel steamers "*Selkirk*" and "*Dawson*," left White Horse for a voyage of 450 miles down the Yukon to Dawson, which was reached at 4 p.m. on Wednesday. The scenery of this part of the Yukon, though inferior in grandeur to that of the Coast and the Coast Range, is picturesque and varied. The river is formed by the confluence of several streams, coming from numerous elongated lakes, one of which is Lake Bennett, on the summit-plateau of the White pass, and another is Lake Labarge, beginning 25 miles below White Horse and extending 33 miles northward. Through this lake the steamer passes; and a few miles further north the Hootalinqua river, another navigable stream, enters the Yukon. From this point to Fort Selkirk, at the mouth of the Pelly river, the course of the river is tortuous, with many islands and peninsulas, and at some places considerable rapids. At Five Finger rapids the passage is very narrow; and sometimes ascending vessels have to be warped through by means of a wire cable attached to the rocky shore and passed around a



Reid's Falls near Skagway.

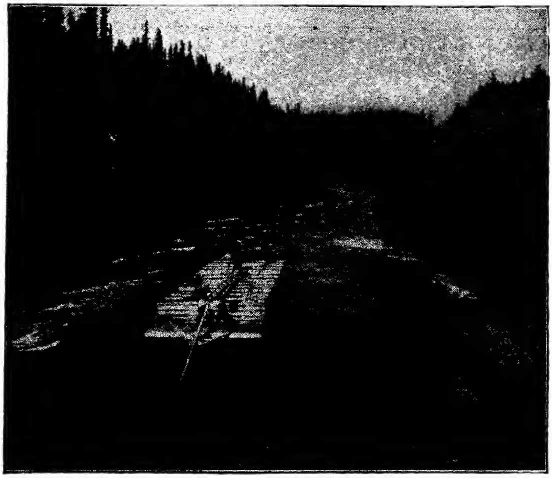
capstan on board. (Upon the return voyage of the party, this operation, though not strictly necessary at the time, was performed for their entertainment.)

Lake Bennett.

Lake Bennett.

On the evening of July 11th, a brief stop was made at the Tantalus coal-mine, 14 miles above Five Finger rapids. Here several steeply-tilted seams of bituminous coal have been opened by tunnels from the river bank. Lignite is mined below Dawson, and used in that camp.

An interesting feature of the banks of the Upper Yukon in the region drained by the Lewes and Pelly rivers, is a peculiar and persistent narrow band of white volcanic ash, underlying the soil, as exposed in the soft, eroded bluffs. This



Scowing thorough Miles Canyon, near White Horse.

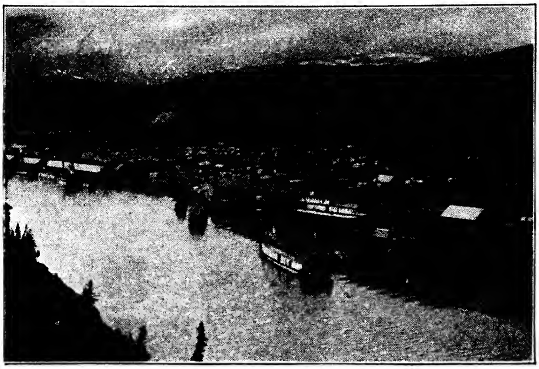
Shooting White Horse Rapids, near White Horse.

layer was noticed by Schwatka,* and has been described by Dr. George M. Dawson,† who deems it to be the result of the tranquil, wide-spread descent, like a snow-fall, of the fine ashes of a single volcanic eruption. It ranges from half an

* *Along Alaska's Great River*, p. 196.

† *Geological Survey of Canada, Annual Report, New Series*, vol. iii., part 1 (1887-8), p. 43 B.

inch to more than a foot in thickness, and in some places it has been accumulated to the depth of 3 ft. and more, being in other places correspondingly thinned or removed. Apart from the general diminution towards the edges, due to increasing distance from the source (influenced also by the direction of prevailing atmospheric currents), Dr. Dawson thinks it was pretty uniform in depth; and,



View of White Horse, Y. T., taken at Midnight, June, 1902.

upon a critical consideration of all the observed facts, estimates it to cover at least 25,000 sq. miles, with an average depth of 3 in., representing a volume of 1.18 cu. miles of ash, equivalent to something less than a cubic mile of solid material. Mt. Wrangell is the nearest known volcano, and may have been the source of the deposit. From sundry indications, Dr. Dawson infers that the eruption must

The Granite Bluffs, near Dawson, Y. T.

have occurred several hundred, yet not more than a thousand, years ago. Similar deposits of volcanic ash are not unknown. One which occurred in Alaska in 1825 is reported to have covered the whole peninsula with ashes. The ash-bed here described consists chiefly of volcanic glass, largely in elongated shreds, like "Pele's hair," together with minute crystals and crystalline fragments of sanidine, hornblende, and probably of other minerals.

Dawson.

On arrival at Dawson, Wednesday afternoon, July 12th, the members of the party were distributed to hotels and private residences, where they found most comfortable entertainment during their stay.

The afternoon was spent in visiting the numerous jewelers' shops, where unique souvenirs, made in Dawson, and exhibiting the coarse gold of the Klondike, arranged in pins, chains, bracelets, and transparent lockets, are sold. The scales and small nuggets used for this purpose, from a millimeter to a centimeter in diameter, are water-worn crystals or aggregates of crystals, which show in many instances, though much battered and deformed, the remains of faces and rounded angles.

Birds-Eye View of Dawson Looking up the Yukon River.

An exhibition of specimens, hastily collected by Mr. Eugene Beraud, was also examined with much interest. It contained many samples of gold- and silver-bearing quartz; barytic lead-ores; slabs of native copper from the head of White river, looking as if they had come from one of the Lake Superior "mass-copper" mines; and curious rocks, fossils, heads of large game, furs, etc.

The visitors were cordially received and registered at the American Consulate by Vice-consul Woodward.

At 9.30 p.m., a public reception was given at the Government House, where Commissioner W. W. B. McInnes and his wife, assisted by Major Z. T. Wood, Commandant of the Northwest mounted police (late Acting Commissioner of the Yukon

Territory) and Mrs. Wood, together with the leading citizens and ladies of Dawson, gave to their guests a delightful welcome.

The Klondike Mines.

At 9 a.m. on Thursday, July 13th, the party, attended by members of the Reception Committee and other citizens, left Dawson in wagons for a drive of two days up the Klondike river, Bonanza and Eldorado creeks, thence over "the Dome," and down Gold Bottom and Hunter creeks. The night was spent at the mining town of Grand Forks, where surprisingly comfortable lodgings and excellent meals were furnished.

For the following outline of this excursion, the "*Dawson World*" and the "*Dawson Daily News*," the admirable sketch by J. C. Gwillim, M.E., in the "*British Columbia Mining Record*" for August, and the information given by the Yukon Reception Committee, have furnished the larger part of the material.

The first day presented abundant opportunity for the study of various methods of alluvial gold-mining, by open-cut, steam-shovel, scraper, traveling bucket, dredge or hydraulic jet; and "clean-ups" were made in the presence of the party, yielding respectively coarse gold of the estimated value of from $5,000 upwards. A plant of great technical interest was that of the Pacific Coast Mining Co., at claims No. 6 and 7 Below, on Bonanza creek. Here the so called "white channel," an auriferous ancient river-bed, crossing (like the "blue lead" of California) the present topography of the country, and lying two or three hundred feet above the present streams, is worked by the hydraulic method, by means of heavy pumping-machinery, which not only lifts the water of the Klondike but delivers it, under the high pressure required for hydraulic mining, at the face of the auriferous deposit. The plant comprises a cross-compound, high-duty, fly-wheel, corliss-valve pumping-engine, with 22 by 44 in. cylinders, and 36 in. stroke, built by the Snow Steam Pump Works, Buffalo, N. Y., and having the capacity of lifting to 300 or 400 ft., at 37 revolutions, 3,000 U. S. gallons of water per minute. There are also 4 water-tube boilers, with aggregate capacity of 328 h.p.; another compound duplex pumping-engine (capacity, 1,500 gals. per min.); and the necessary machine-shop and plant for electric lighting. The company gives the cost of pumping per month as $2,200 for labor, $2,600 for fuel, and $600 for supplies, or (for 25 working days) $216 per day. This expenditure furnishes 270 miners' inches per day, representing a cost of $48 per sluice-head (60 miners' inches). The efficiency of one miners' inch of water from the middle of June to first of September is 8 cu. yards. This high duty per inch is due to the fact that the gravel rests on an even bed-rock high above the present creek level, thus giving plenty of grade for hydraulicking purposes, and that the struction of the gravel

is such that it washes readily. Moreover, the ground is well thawed at this season, which makes a large difference in the daily output. The estimate based on these data by Mr. E. E. Andrews, the company's manager, shows 2,100 cu. yd. washed per day at a cost of $216 for pumping and $200 for other items (including general expenses), or about 20 cents per yard.

This high cost could not be borne by a deposit of ordinary value per cu. yard. But Mr. Andrews estimates the amount of ground, belonging to the company which can be treated profitably in this way at more than 1,500,000 cu. yd.—in addition to which, it possesses much other ground on the lower level, which it develops by shafts and tunnels. Unquestionably, if high-level streams, giving by gravity the necessary hydraulic pressure, had been available, the company could have exploited the "white channel" with greater ease and profit—a proposition which emphasizes the need, and indicates the profitable character, of bringing to this region an adequate supply of water under the pressure of gravity from the mountains which surround it.

At the Discovery claim on Bonanza creek, a dredge in operation was studied with much interest, under the guidance of Mr. J. Moore Elmer, the superintendent. It is of the old Risdon type, and has a capacity of 500–600 cu. yd. in 24 hr., employing 3 men in three 8-hr. shifts. (A description of the much larger dredge now building under Mr. Elmer's direction is given in the account of the next day's trip.)

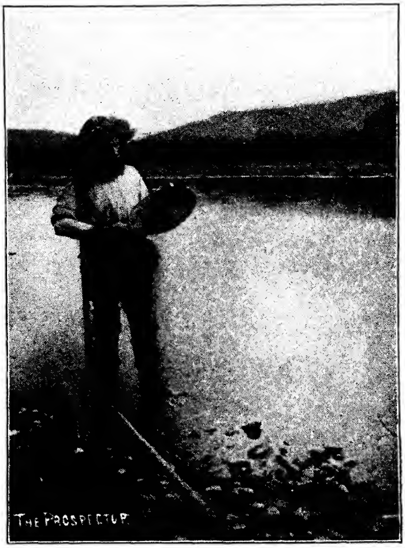
At claim No. 46 Below, on Bonanza creek, the Syndicat Lyonnaise du Klondike extended a hospitable reception, including a luncheon, followed by a clean-up from its sluices which yielded about $6,000 in coarse gold. The ladies of the party were here assisted to "pan" samples of earth shoveled from ground not yet worked. One of them obtained several dollars. This company owns also a large concession, 5 miles long by 1 mile wide, in Ten Mile creek, about 62 miles from Dawson.

Later in the day, after dinner at Grand Forks, the Stanley claim, No. 25, Eldorado creek, was visited, and a magnificent clean-up of about $20,000, from a little over 3 days' run of gravel near bed-rock, was witnessed with great surprise and delight.

At Gold Hill, the operation of a heavy stream of water brought through a 20-in. inverted pipe-siphon afforded an illustration of the economy of this method, whenever it can be employed; and at the Norwood claim, on Magnet hill, the visitors observed a similar plant, nearly completed, and including an inverted siphon, 3,500 ft. long, and expected to deliver 1,000 miners' inches of water at a pressure of nearly 300 ft. head.

On the morning of Friday, July 14th, the party left Grand Forks for "the Dome," a summit 10 miles distant, and 4,250 ft. above tide, which commands a magnificent bird's-eye view of the auriferous gulches of the region. Indeed, they seem to have their common origin in this mountain, and to radiate from it in all directions. At the summit, an abundant luncheon was served in a large tent erected for the purpose; after which, the procession of carriages descended at a rapid pace by way of Hunker creek, everywhere received with cheers and waving of handkerchiefs by the inhabitants.

Gold Bottom was reached in an hour, and a brief stop was made, to permit the inspection of old-fashioned "rockers" in operation. From No. 46 down the valley, the sound of steam-whistles from the mining-plants (at one time, there were eight going at once!) was added to the other demonstrations of welcome. At No. 76, a pause was made for the hasty inspection of the Ben Levy quartz-claim, and its ore-body; and another brief interval was given for a glance at the workings of Preido's claim, below.



Prospecting on the Yukon.

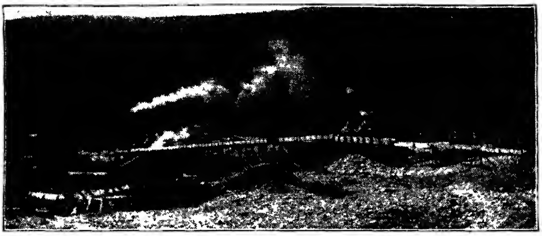
At Bear creek, which was reached after 7 o'clock p.m. (but the clock had little to say at this season, when daylight lasts all night!) dinner was served, and the famous big dredge under construction was inspected with great interest.

This dredge has been built for the Canadian Klondike Co., under the direction of Supt. J. Moore Elmer, a member of the Institute. Concerning the general subject of dredging in the Yukon Territory, Mr. Elmer sent to the Local Committee an interesting statement, part of which follows:

"As a result of six years' experience, operating a 3-ft. Risdon dredge in the Klondike district, and by careful observation during that period of the auriferous deposits of the country and the climatic and other conditions peculiar to it, I am convinced that the vast Yukon basin from the Rocky Mountains to the Behring Sea contains immense areas in which this form of mining can be profitably carried on. . . ..

"In California, where gold-dredging has reached its highest state of development, extremely low-grade dirt is being profitably worked, and this after paying almost fabulous prices for land which but a few years ago was considered absolutely valueless for mining purposes. True, all the conditions in California are exceptionally favorable for cheap operation. They can operate 365 days in the year, while our season is but half that length (not taking into account that during half of that time there is continuous daylight, a feature of no inconsiderable value). Our advantage lies in the high values in the ground, and it is these high values that especially commend the field for dredging operations.

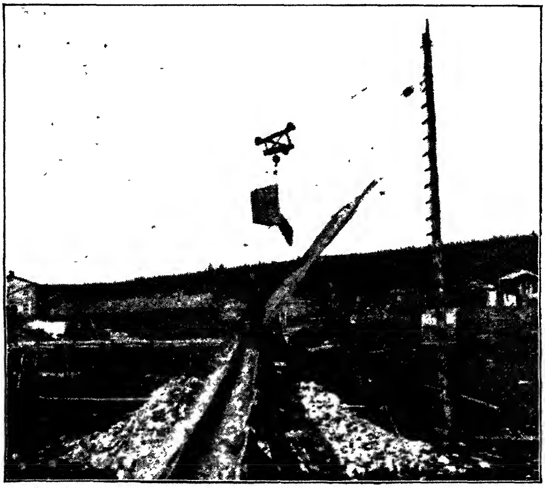
"The climatic conditions are not as unfavorable as might be supposed by those unacquainted with the region. . . . The winters are cold but not severe, due to the dryness of the atmosphere and the absence of high winds. Blizzards are unknown. While actual dredging operations cannot be carried on during the winter, that season is ideal for the cutting and yarding of wood. Men engaged



Mining by Machinery in the Klondike.

in that operation seldom find it necessary to lose a day on account of the weather. The prospecting-drill can also be worked to the best advantage during the winter.

"Our placer-gold is found mostly in bed-rock, and the ground is generally frozen. This combination of circumstances may seem to the uninitiated a fatal objection. It presents a difficulty, to be sure, but not an insurmountable one, as



Mining by Machinery in the Klondike.

the results I have been able to accomplish will amply testify. It adds to the cost, but the high values obtained justify the expense.

"There are countless thousands of acres in the Yukon basin that are suitable for dredging, and that would pay handsome returns on the investment if judiciously made. The country is capable of thorough investigation, and it is the thorough and intelligent investigator that the country needs. When the true con-

Thawing Frozen Gravel by Steam in the Klondike

ditions become generally known, by reason of such investigation, I believe I am not too optimistic in predicting that the number of dredges in operation in the Yukon will be limited, for a number of years, only by the capacity of the manufacturers to fill orders.

"No. 26 above Discovery," Eldorado Creek.

G, and Forks, Y. T., viewed from Gold Hill.

"It must not be inferred that all placer-ground in the Yukon is suitable for dredging. On the contrary, much ground that can be profitably worked by other processes would prove a failure for dredging purposes.

"In order to succeed with a dredge in the Yukon the first desideratum is careful selection of the ground as to its suitability for the purpose; then, given a dredge properly constructed to meet the conditions under which it is to be operated, and intelligently managed, the Yukon presents an almost limitless field for the profitable investment of capital in mining gold by the dredge-process."

Mr. Elmer has shown the courage of his convictions, and his company its faith in his judgment by the expenditure (as reported) of more than $250,000 on this plant. The dredge is second in size only to the mammoth machine at Oroville, Cal, which handles more than 3,000 cu. yd. of earth daily. This one is expected, under the less favorable conditions presented by the frozen gravel of the Klondike, to handle, in 24 hr., 2,000 cu. yd., digging 35 ft. below the water-surface, and throwing the tailings 22 ft. high and back 90 feet Each of the 65 buckets weighs 1,700 lb ; and the grizzly, 27,500 lb. , and the spud, which steadies the barge from the stern, 10 tons, while many other pieces weigh from 6 to 8 tons each. The hull of the barge measures 100 by 33 feet. The electric power is generated by three 150 h.p. boilers and a 600 h.p. Westinghouse-Parsons turbine-engine.

The speed, energy and skill with which the construction of this great plant has been pushed, may be inferred from the fact that on July 9th the first material, weighing 800 tons, arrived at Dawson. Mr. McConnell, the freighter, undertook to have it all at Bear creek within 30 days, and, employing 20 teams, completed the job in 26 days. Meanwhile, the construction had to be begun; and before August 4th the frame was about 45 ft. high, and the hull was almost ready to be launched. (These latter particulars are taken from the *Denver Daily Mining Record* of August 4, 1905.)

The following dredges and steam-shovels were already at work in the Yukon district: Ogilvie Dredge Co. (Klondike river); Lewes River Dredging Co. (Discovery claim, Bonanza creek); Canadian Klondike Co. (Bear creek, 2 steam-shovels); A. D. Fields (No. 60 Below, Bonanza creek); and Frank Phiscator (No. 2, Eldorado creek, 2 steam-shovels). And, besides the large dredge above described, the Williams dredge, to cost $100,000, on Klondike river, below Ogilvie bridge, and the Canadian Dredging and Mining Co.'s dredge, to cost $75,000, on No. 89 Below, Bonanza creek, were under construction.

Dawson's Farewell.

The party reached Dawson shortly after 11 p.m., but many still retained energy enough to attend a social dance, given in their honor at Eagle Hall.

Saturday, July 15th, was spent in resting, local sight-seeing, shopping, etc., and in preparations for the departure which had been fixed for that night. But before that event there was a

farewell banquet, in the Hall of the Arctic Brotherhood, terminating a little after midnight. Hon. W. W. B. McInnes, Commissioner of the Yukon Territory, presided, and after toasts to the King and the President had been suitably honored, proposed "Our Guests, the American Institute of Mining Engineers," accompanying the sentiment with a graceful address of welcome, concluding as follows:

"We hope you will come again in the future, either as investors or the advisers of investors; and I can assure you, on behalf of the Government, Territorial and Federal, and on behalf of the business men of Dawson, that we will do all in our power to make such investments profitable and absolutely secure. And I have this to say also: that, whether you be on pleasure bent or on business bound, you will always find a sincere and hearty welcome!"

Acting President R. W Hunt and Secretary R. W. Raymond responded for the Institute. Dr. Raymond's address is here printed, by request, as giving a view of the industrial situation as it appeared to the visiting engineers:

"I confess that I came with the impression that this was a region in which man was fighting a hard battle with nature, all of whose forces and passive resistances were arrayed against him at every point. That impression has been considerably changed I have seen that nature is not wholly hostile to you Along with her bounty of gold, she has blessed you with an abundance of water—the agent which deposited that treasure, and upon which you must chiefly rely for its extraction

"This water furnishes you also with a trunk highway for transportation, and with sources of mechanical power, to which may be added, in your beds of coal, another essential of your industry. Man has done much already to promote the industry of your territory Good roads, good laws, good government (with a good governor, too!), good, honest, earnest people—these things are more important, in the long run, than conditions of climate or distance

"But I must confess to another impression with which I came here, namely, that this region was one in which a few deposits of gold of extraordinary richness were to be swiftly exploited and exhausted—probably at great expense and relatively reduced profit—after which it would be necessarily abandoned again to the Indians and the wild beasts, as no longer able to repay the labors of man

"Is that true? It might be There have been such regions, but I do not think this is one of them. The Yukon territory depends for its future upon the extent of the rich gold-deposits now workable at a profit, the extent of the deposits available hereafter; and the resources which may be made to reinforce these, and would be left if these were gone. The latter need not be considered now, for the former, in my judgment, ought to be sufficient for your children and your children's children.

"But rich clean-ups from placer and hydraulic mines, like rich yields in stamp-mills and furnaces, are not proofs of permanent prosperity. When only rich returns are made, it is not because everything in the district is rich, but because what is not rich cannot be worked without loss. There never was a mining district in the world that contained all rich and no poor ore, all coarse gold and no fine, any more than there ever was a cow that gave all cream and no milk. Where such concentrations of value as those which we have seen in this neighborhood are shown, you may be sure that there are immeasurably larger quantities and values scattered through inferior material, and the mining industry becomes a really profitable business, giving steady and abundant employment to labor, dividends to capital, and a healthy atmosphere, both of trade and of social life, to the community, in those regions where it operates on low-grade material.

"We are all interested, of course, in seeing a skillful expert show us a dollar's worth of nuggets and scales of gold to the pan; but those of us who have followed the business of mining for years are looking quietly away from that pretty exhibition, and trying to estimate the available ground which, yielding less, ought, under suitable conditions and proper handling, to *pay* more and *last* longer. It is not what this Territory can do on a first spurt, but what it will do when it gets its second wind, that fixes its destiny for the present century.

"Forty years ago a certain silver-mining district in Nevada was famous for the extraordinary richness of its ores—ruby silver, silver glance, etc. When, as United States Mining Commissioner, I visited that region, they boasted to me that not one ton of ore had ever been milled in the district that did not yield at least $125. But this proved only that they were unable to treat with profit at least nine-tenths of the ore they had to mine in order to obtain the one profitable tenth; and the yield of that rich tenth was in reality wholly wasted upon the expense of mining the rest; so that at that very time when the average yield of the ore milled was more than $100 per ton, the total bullion-product of the district was only about equal to the cost of feeding its inhabitants.

"I have repeatedly made similar calculations, with similar results, concerning mining districts in which rich material only was treated for gold or silver; and though I have not reckoned with regard to the Yukon territory, I feel quite sure that the same has been practically true here. One of the ladies of our party, returning from the brilliant excursion of yesterday and the day before, and receiving at the hotel the bill of a Dawson laundry, summed up the situation by saying, 'The dirt here is certainly awfully rich, but the washing is awfully dear!' And an ingenious gentleman among us, of large diameter and corresponding surface-area, purposes to take his auriferous soiled linen out of the Territory, just as it is, and have it treated at home by somebody who will accept as pay the amount of gold to be subsequently panned out of the wash-tub!

"Seriously, what you need, first of all, is such a reduction of costs as will increase both the product and the profit of every man, whether laborer or prospector or employer, in your community. The fundamental element—the auriferous area itself—you have in abundance. Even of the rich bonanzas you will, without doubt, discover many, rivaling those which you are now exploiting. There is cream yet to be skimmed from the top; but, if I am correct in my view, the cream will be chiefly valuable as showing you where milk is, whether in streams or in quartz! Of such milk, there is clearly a vast supply stored up for you, but to get it to market you must use what milkmen all over the world are reported to use, namely, water.

"The water question is the 'burning question' of the Yukon Territory to-day. Nature has given you the means of solving that, also, and stands ready to assist

you if you work with her. You can, if you choose, raise the water by main force to the level at which you need it. We have seen a magnificent sample of that bold defiance of nature within the past two days. '*C'est magnifique, mais ce n'est pas la guerre.*' It is splendid ; but, as a general proposition, it is not 'biz.' For water can be brought down more easily than forced up, and the water you want is not in the Klondike or the Yukon, but in those mountain streams which feed them.

"In the great enterprise of utilizing that vitally essential element of a permanent industry, I feel sure that this Territory will receive, as I think it fairly deserves, the encouragement and assistance of the Government of the Dominion of Canada

"It would be unbecoming for me to volunteer suggestions as to government policy, but I may be permitted to define my own view. I am not a friend of so-called paternalism or State socialism. I think that, outside of the maintenance of law and order and the enforcement of contracts, the less a government has to do, the better.

"Moreover, if I have read correctly the history of your country as well as my own, the attempt of the Government to supplant private enterprise by directly executing great works for the good of particular industries, has not resulted so advantageously as to make us yearn for its unnecessary repetition. It may have been sometimes necessary, but it has never been in itself desirable

"On the other hand, your Government, like ours, occupies a double position It is not only a sovereign, but also an owner of land from which it derives, through sale or royalty, a revenue. So long as the Dominion collects, as land-owner, a percentage of your product, it may fairly be called upon to manage its own property with at least ordinary wisdom, and to facilitate and assist the increase of that harvest of which it receives a part

"I must frankly confess that my own Government has thus far shown little of this wisdom in its administration of the Territory of Alaska, from which it has received much, and for which it has done less than it might wisely do The Dominion Government and the Governments of the Canadian Provinces have been more liberal and far-sighted Indeed, I am inclined to suspect that, in some cases, they may have gone too far But, in spite of any such mistakes, if any there have been, the net results of Canadian policy are seen to-day in a solid advance which has surprised your warmest friends and surpassed your own prophecies

"In conclusion, gentlemen, let me urge upon you the importance of unanimity in pressing the just claims and supporting the vital interests of your Territory. The voice of a majority—even of a very large majority—is not enough for your need. A small dissenting minority—yes, even a single strident opposing voice—can work immeasurable mischief in the consideration by a distant executive government, or the discussion by a distant parliament, of proposals and requests affecting the interests of a newly opened, largely undeveloped and little-known region. If *you* cannot agree about yourselves, how can you expect remote strangers, however well disposed, to agree about you? I trust you will not deem me impertinent when I say that, in my judgment, any division among the citizens of the Yukon Territory on the lines of political parties elsewhere—in Victoria, Ottawa or London—would be the height of folly. Why should anybody be 'Conservative,' for instance, in a country which has no past to 'conserve,' but only a glorious future to conquer?

"On the other hand, if you act together, in warm—yes, white-hot—yes, *fluid*—unanimity, obliterating all distinctions of personal ambition or party politics, there is nothing you can properly desire which you will not irresistibly achieve!

Our generation has had an object-lesson concerning the power of such unanimity, which we may well heed. We have seen the small nation of Japan victorious over a more powerful but less enthusiastically united foe. I know of nothing in the history of war more wonderful than the skill, devotion, tenacity and patience which lately captured one of the strongest fortresses in the world. If there be a parallel, we must seek it in the annals of peace, a thrilling chapter of which records the conquest of this region by the dauntless and persevering pioneers of the Yukon and the Klondike. Be of good cheer! You have won your Port Arthur, and it now remains for you to make a permanent ally of that Nature which was at first your foe, and to arrange with her and with one another the wise terms of a permanent and profitable peace!"

Hon. J. T. Lithgow, Comptroller of the Territory, inproposing the toast of "The Mining Industry," said:

"I desire to join with you, Mr Commissioner, in expressing the gratification which is felt by the residents of the Yukon Territory in the visit of the American Institute of Mining Engineers It is very gratifying to us that the ladies have accompanied the party, and we trust that their visit will prove both pleasant and profitable It is a matter of regret to me that I have been asked to propose this toast, since during my seven years' residence in this territory I have had practically nothing to do with mining, except to collect the royalty from miners after they had extracted the gold from the ground (Laughter.)

"The first strike of gold was made in this district on August 15, 1896, by George Carmack and two Indians. Many other prospectors had been in the country, and it is really due to the adventurous spirit of Bob Henderson (who was engaged in mining on what is now known as Hunker creek, and who had visited the mouth of the Klondike, where the Indians were camped) that the rich discovery was made which electrified the world

"A number of miners from Fortymile, Eagle, Circle City and other places, on hearing of the strike, came up here, and spread the news to the outside world. Then took place one of the greatest stampedes ever known since the discovery of gold in California in 1849, and later in Australia in 1862 It is estimated that some 80,000 men, many of whom were utterly unable to cope with the great difficulties incidental to placer-mining in those days, rushed into this region

"The introduction of steam-thawing apparatus, hoisting- and pumping-machinery, etc, and the discovery of gold on the higher levels, greatly helped to increase the product of the Territory.

"The first creeks to be worked were Bonanza and Eldorado From the latter creek, which was developed for three and one-half miles, it is estimated that there came $25,000,000. I know of one claim, 500 ft long, which produced a million. This figure is based on the royalty actually paid—certainly a very good basis on which to calculate the product of this claim The fact that you engineers have visited the creek and found it still being worked with a large output, further testifies to its great wealth.

"The total gold-production of the Yukon Territory, up to the 31st December, 1904, is placed at $114,186,000 This, I think, is certainly a very conservative estimate, much below what was actually produced. Those of us who have resided here since 1898 realize that the first very rich claims are nearly worked out, but that the lower-grade gravels, if worked economically, will produce millions and millions for years to come. The introduction of dredges has begun, and they are now successfully worked.

"This is the present position of our placer-mining. It is a matter of regret that the engineers did not have time to visit the outlying districts and be convinced that what they saw in the Dawson district was but a drop in the bucket.

"Those of us who have a knowledge of the Duncan, Hiatt and other tributaries of the Stewart river, are aware of the immense deposits which are yet to be opened. After a time we shall hear of the development of the Kluane and other large districts, many of which are as yet unnamed, but are known to contain auriferous gravel deposits.

"There are many indications of good quartz-veins in the country, and the time is not far distant when stamp-mills will be in operation. The rich deposits of copper at White Horse, the abundant supply of suitable coal and fluxing material in close proximity, and the occurrence at various points of high-grade silver-lead ores, lead us to believe that, in a very short time, these products will add materially to the mineral riches of the Yukon."

Mr. C. W. Goodale, Gen. Manager of the Boston and Montana Copper Co., replied to this toast, adducing the Butte district of Montana as an instance of the development of other mineral resources than those which first attracted miners to it. Butte began with placer-mining for gold; then became a silver-mining camp, when the first ore-bodies were found; and is now justly famous for its production of copper. Mr. Goodale urged the importance of explorations for deep deposits of gold, silver, copper, lead, etc., while the exploitation of the placers was still active, and before the approaching exhaustion of such mines should cause diminution of population, scarcity of labor, and lack of speculative interest and energy, in order, as he expressed it, that the two kinds of mining "might overlap, and thereby give continuity to the prosperity already enjoyed by this camp."

Mr. E. V. d'Invilliers, of Philadelphia, Pa., being also called upon to reply to the toast of "The Mining Industry," responded with brief but interesting remarks, vindicating the fundamental importance of coal as a primary necessity to the development of all mineral industries, and expressing a strongly favorable opinion of the value of the Yukon coal-fields.

Dr. Joseph Struthers, Assistant Editor of the *Transactions* of the Institute, and formerly Editor of the great American statistical publication, "The Mineral Industry," being called upon, responded with a pertinent and forcible recommendation of the preparation and circulation of trustworthy statistics as a much more effective agency of real progress in the development of a new mineral region, than the imaginative and exaggerated ac-

counts of enthusiastic prospectors or interested promoters. In this respect, the carefully prepared, temperate and comprehensive pamphlet of the Yukon Committee was worthy of high praise.

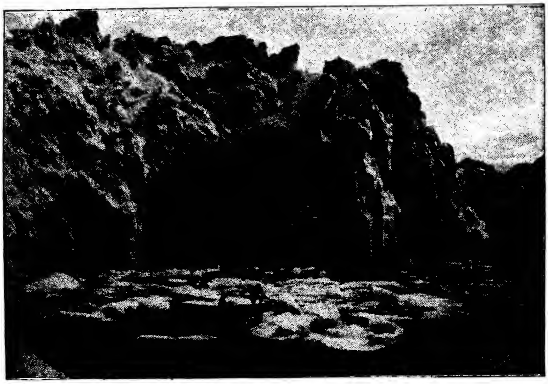
Mr. D. W. Brunton, of Denver, Colo., a past Vice-President of the Institute, was likewise called upon, and expressed for himself and his associates the favorable opinion of the natural resources and industrial, commercial, governmental and social conditions of the Yukon Territory, which they had formed during their visit.

Mr. Charles Macdonald, of Dawson, speaking for Dr. Antony Variclé, presented to the Institute a magnificent album of photographs of Yukon scenery, etc. This folio, about 22 by 33 in. in size, is bound in flexible caribou-leather, embossed and decorated, the central design being a placer-miner's pan, containing scales of Klondike gold, while from this pan a stream of gold (in particles cemented to the caribou-leather) descends to the lower edge of the cover. Among the photographs, which are not only typical and interesting, but remarkably fine, artistically and mechanically, is a panoramic view of Dawson and vicinity, 11.5 in. wide by more than 5 ft. long, and necessarily constituting a "folder."

Dr. Varicl6, who has been elected a Life Associate of the Institute, is a highly-esteemed citizen of Dawson, heretofore known in scientific circles as a member of the Aeronautical Society, and an author on that subject, but more recently distinguished as the originator of a new scheme of Arctic exploration, of which an early practical test (in 1906) now seems probable. The essential novelty of the plan consists in the utilization of the method employed by the Northwest Mounted Police in many adventurous explorations not as famous as they deserve to be—namely, the employment of both mules and dogs for transportation, and the killing of the mules as food for the dogs, when there is no longer forage for the former. Of course, a "dash" thus supported would start from a base of supplies previously established as far north as practicable. Before hearing of Dr. Varicl6's enterprise, the writer had received from an officer of the Mounted Police an intensely interesting account of this method of exploration, at the close of which he asked, "Why haven't you ever gone to the North Pole in that way?" The serious *naive* reply was: "Well, we never have been ordered to do that!" The further question, "If you should receive such orders, do you think you could carry them out?" elicited the answer, "I think we could probably go as far as there is any land." This touches the heart of the problem of reaching the Pole. But there seems to be little doubt of the success of the method for the extension of Arctic explorations on land, at least.

The banquet had been inaugurated by a march around the

tables of Mr. Anderson, a Scotch citizen of Dawson, and a famous piper (whose brother was said to be piper to King Edward), over 6 ft. tall and of splendid physical symmetry, who was dressed in full Highland costume. The same magnificent figure tunefully led the procession which marched, after the feast, to the steamboats at the docks. Midnight had nominally passed; yet sufficient day still lingered in the sky to permit a photograph ot the scene to be taken. The people of Dawson (who apparently did not go to bed at all during the visit of the party) lined the streets, and subsequently crowded the piers, bidding their guests farewell with waving handkerchiefs, songs



Taku Glacier.
(Copyrighted by Miles Bros. of San Francisco).

and cheers; and when at last the two steamers cast loose, and began their return-journey up the Yukon, the vanishing picture of this hospitable multitude worthily closed a unique and unforgettable episode.

Homeward Over the Canadian Pacific.

The return-trip to Vancouver presented few novelties inviting description. One of these was the exceptional view of Lake Bennett, on the summit of the White pass, which happened to be (almost beyond the recollection of the railway-people, who see it every day) unruffled by any breeze, and, consequently, presented in its transparent depths a perfect reflection of the surrounding mountains and the sky above them. Another was the entrance into Taku Bay, where, amid iridescent icebergs,

the steamer floated close to the precipitous face of the great Taku glacier, where it breaks off into the water. And a third was the inspection, at Alert Bay, of a modern salmon-cannery, with its Indian fishermen, encamped with their families in deserted houses; its heaps of freshly-netted fish of gorgeous hue; and its apparatus for swiftly preparing and canning them. There were also at Alert Bay totem-poles, finely carved canoes, and an Indian burying-ground.

Arriving at Vancouver, late Saturday night, July 22d, the party was transferred Sunday afternoon to the special train (the same which had conveyed it westward from New York), and proceeded eastward that night on the Canadian Pacific railway.

It is unnecessary to describe here the sublime scenery of the Frazer cañon, the Selkirks and the Canadian Rockies, through which the main line of this railway passes. The accompanying illustrations represent a few of the many scenes, formerly accessible to hardy and adventurous explorers only, but now to be reached with ease and comfort by ordinary tourists. While it is confessedly impossible to compare, for the determination of their relative rank, the master-pieces of Nature's architecture and painting, this much may be fairly said: that, even after all the glories of the long preceding journey, the members of the Institute party enjoyed during their return-trip new experiences of reverent delight, and were justified in regarding this final period as the climax and crown of all that had gone before.

Stops were made by the special train at Glacier, Field, Laggan, Banff, Calgary, Moose Jaw and Portal, at the times shown in the itinerary already given.

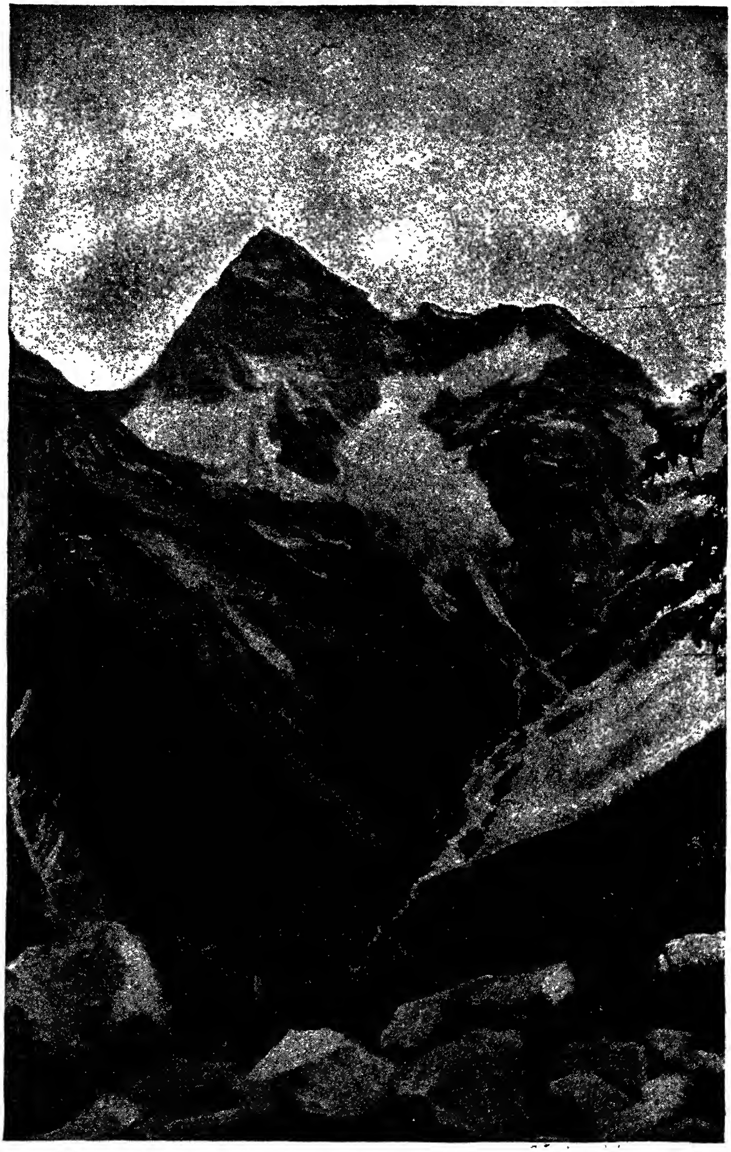
Aside from the æsthetic and social enjoyment of this part of the homeward journey, two points deserve special mention.

1. The first concerns the admirable arrangements of the Canadian Pacific Railway Co. for the utilization of the great scenic attractions of its road. In addition to its well-appointed sleeping- and dining-cars, and its efficient general passenger-service, this company has provided good hotels, roads and trails, Swiss guides for mountain-climbers, excellent souvenir-views and pictorial postal-cards, and, above all, an amazing volume and variety of maps and literature, both illustrative and instructive. Especially praiseworthy is the "annotated time-table," a handy pocket-volume, in which information as to the

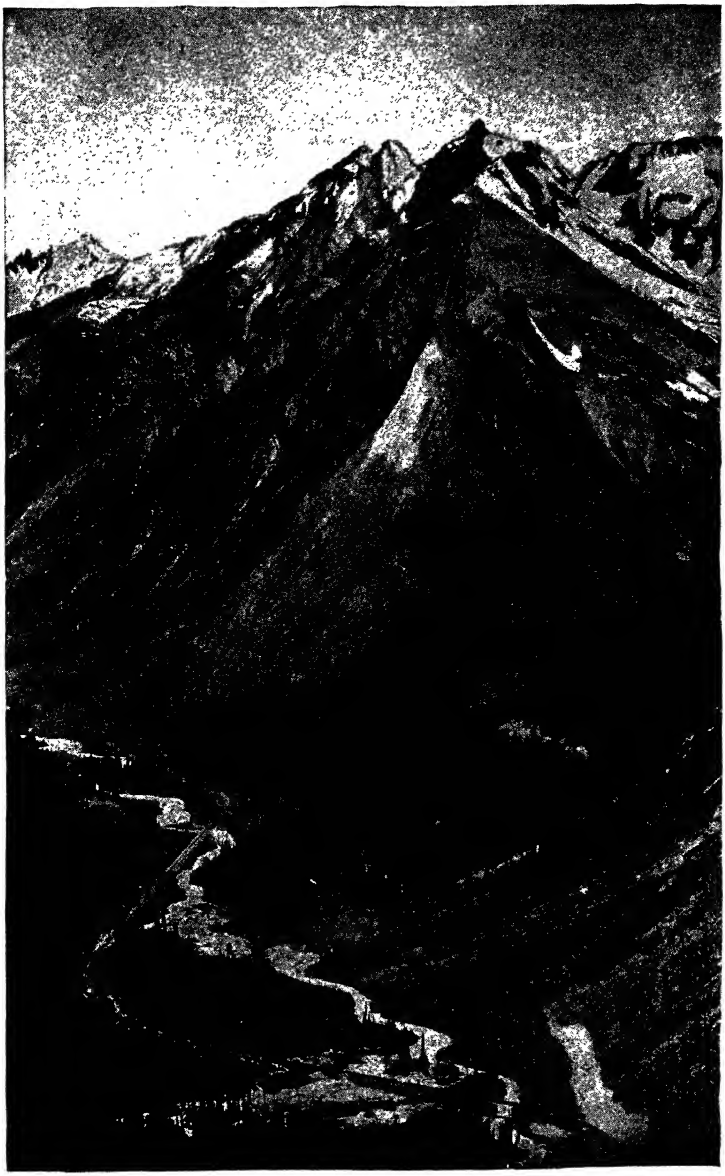
Yale and Siwash Bluff, B. C.

Mount Stephen, Field, B. C.

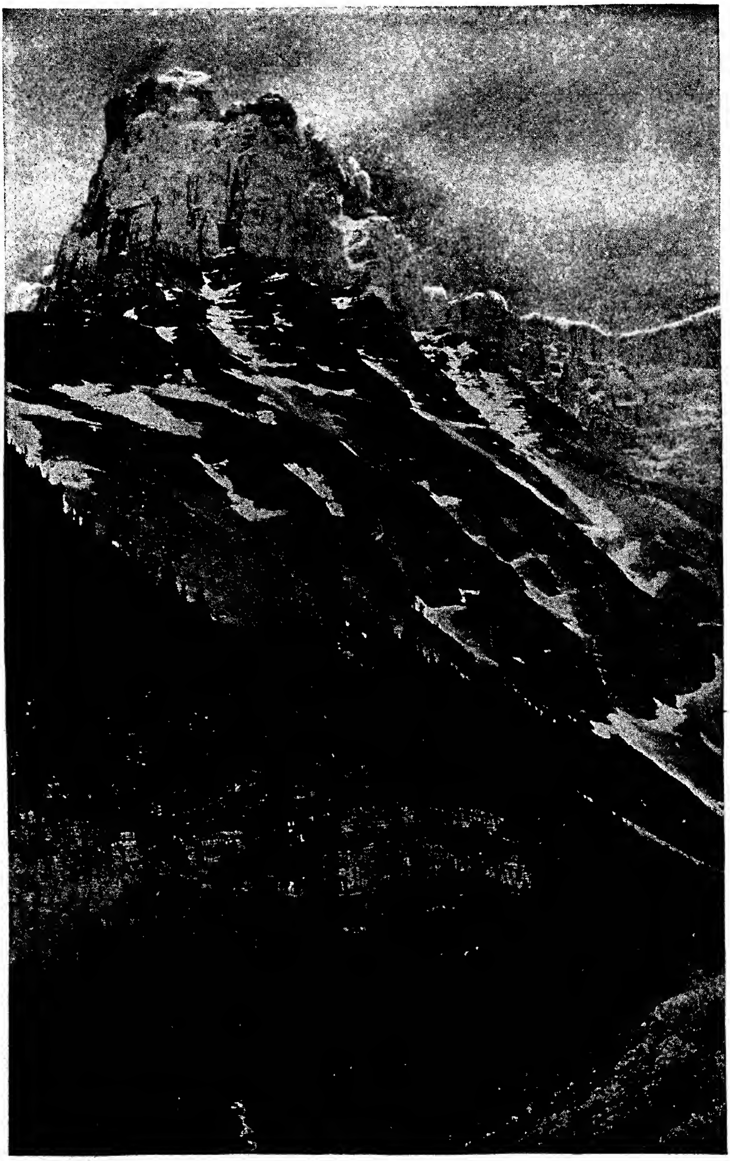
Mount Stephen, from the Eastward.



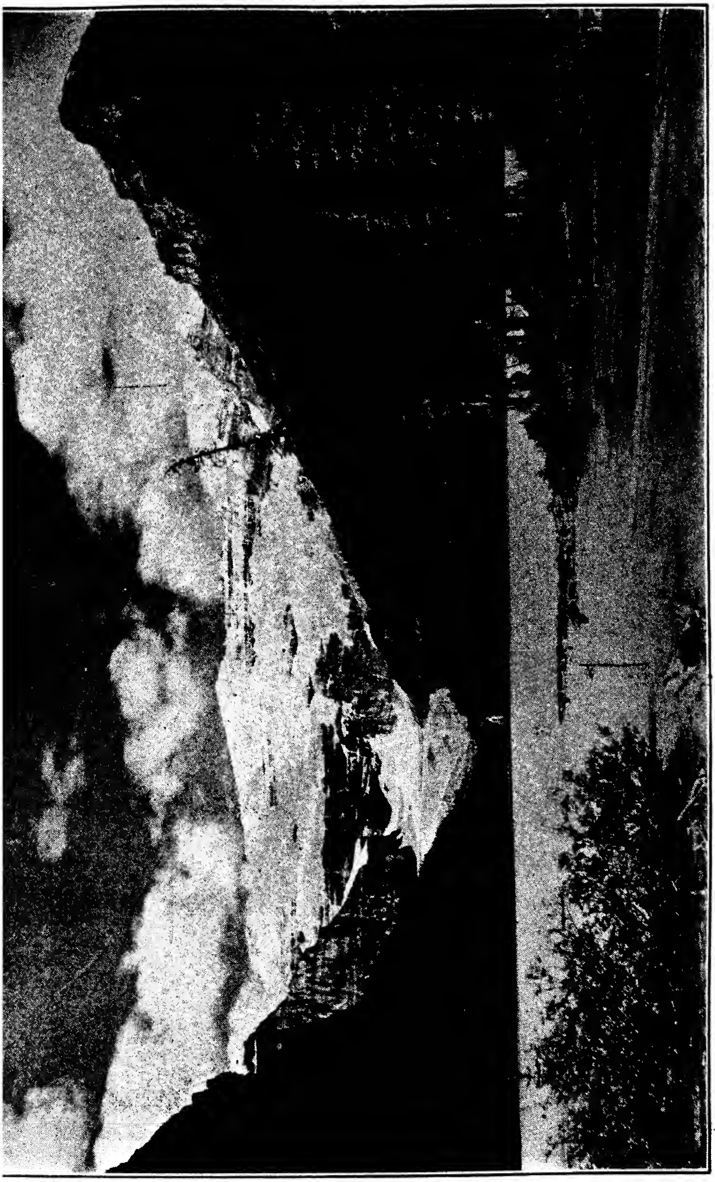
Sir Donald, Selkirk Range.



The Valley of the Illecillewaet.

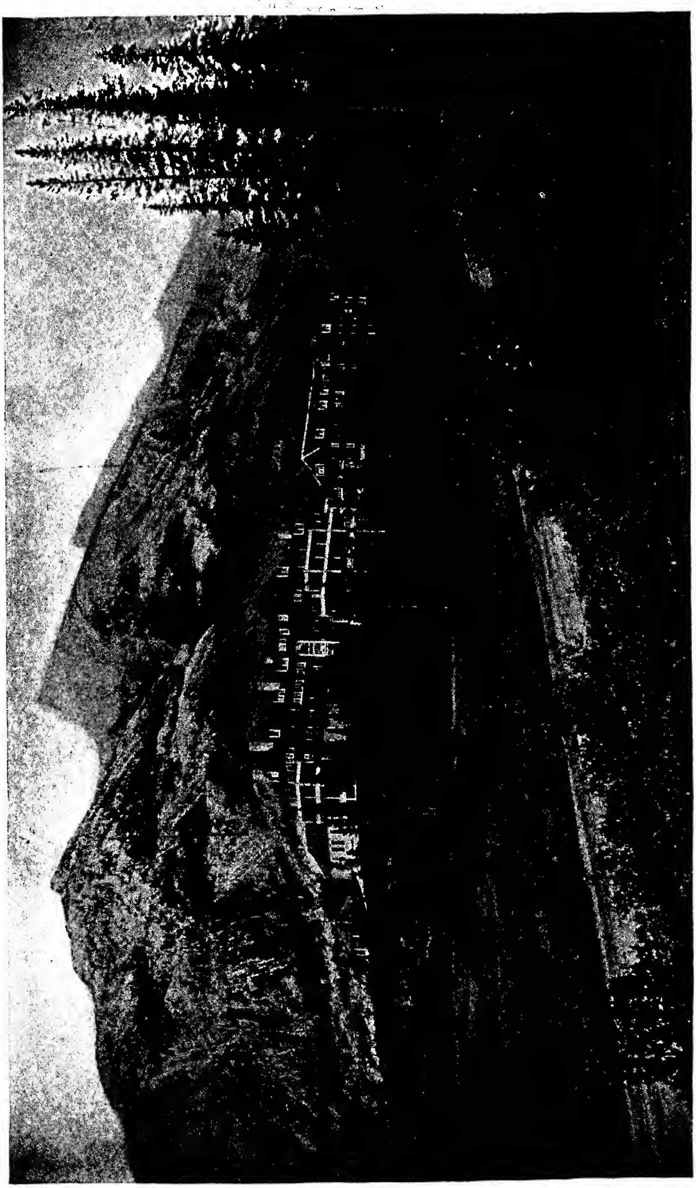


Cathedral Mountain, Continental Divide.



Lake Louise. and Victoria Glacier.

The Three Sisters.

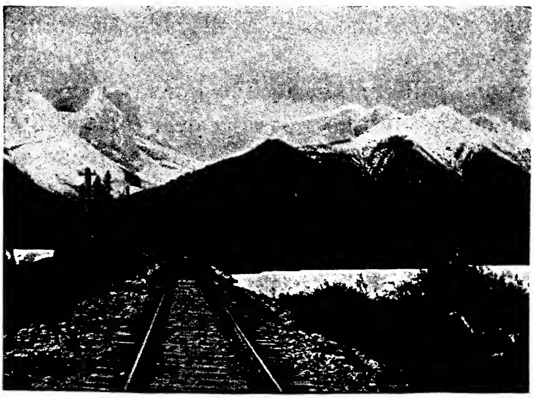


Canadian Pacific Railway Company's Banff Hotel and Mount Rundle.

Lake Agnes and Mirror Lake.

Buffalo at Banff.

Mt. Assiniboine.
(Copyrighted by H. W. Du Bois.)



Farewell to the Rockies.

altitude, geographical and commercial relations, historic associations, etc., of each station is succinctly given, and blank leaves are interpolated for the record of the traveler's personal experiences and impressions. After making the journey with such a book, anybody could write a magazine-article, or lecture in public or private, with full confidence in his underlying facts, and consequent freedom of descriptive superstructure! The money-value of scenery has been exploited in Switzerland and Italy, but not everywhere upon our continent. This company appears to recognize it; and its liberal measures for the accom-

Minnehaha Falls, Minneapolis.

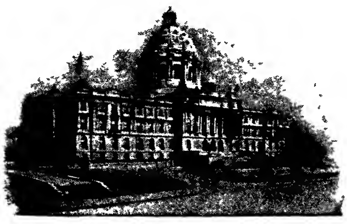
modation of tourists are already, as they deserve to be, a source of growing profit.

2. The second point emphasized by our rapid survey is the astonishing amount of business passing over this road. Already, in some places, four tracks have been put in; and a mere inspection of the numbers on the freight-cars shows that several hundred thousand of them are in use. Of course, the heaviest traffic is east of the mountains, in the immense and fertile wheat-growing region.

At Minneapolis, the party was entertained by two of its members, Messrs. George R. and F. W. Lyman, with a delightful trolley-ride through the city and park, and over to St. Paul.

At Chicago, Mr. and Mrs. Robert W. Hunt gave to their fel-

low-travelers a luncheon at the Auditorium-Annex, after which the party (diminished by the loss of many who had stopped at Minneapolis and Chicago) returned to the train, and proceeded without further extraordinary incident or accident to Philadelphia and New York, reaching the latter city on July 30th, a few minutes ahead of the schedule-time, and thus completing a memorable journey, by land and sea, of more than 10,000 miles, occupying 38 days, and achieved without a single disaster, disappointment, or serious discomfort to any person. Surely this must be deemed a conspicuous instance of the approval bestowed by Providence upon the wise and skilful arrangements of Man!



State Capitol, St. Paul.

PAPERS.

Labor-Saving Appliances in the Works-Laboratory.

BY EDWARD KELLER, BALTIMORE, MD

(Lake Superior Meeting, September, 1904.)*

THE present ruling principle in shop and factory, induced by conditions of keen competition, is to do the greatest amount of work in the shortest time; or in other words, to secure the greatest output at least cost,—a condition which has generally necessitated the substitution of machinery for manual labor.

The chemical laboratory in our industrial establishments has remained a factor of minor importance, and, for this reason, not only has progress been permitted to lag, but the methods of analytical work have been carried on along individual traditional lines. Some works-laboratories are equipped with such conveniences as Gooch filters, suction-pumps, compressed air, shaking-machines, centrifugal machines, crushers, etc., yet there is much room for improvement, particularly in laboratories of metal-smelting and refining plants, in which long series of filtrations and stirrings are performed singly by hand in a slow and laborious manner. There are also many other instances in which collective handling appears rational. As a rule, the chemist wastes much time by such manual labor, which, in a modern establishment and under up-to-date management, could be more advantageously applied to useful chemical work; and such higher chemical work is gradually and surely becoming recognized as an essential extension of old-time methods of assaying. While it may be said that in some laboratories, boys and not chemists do the manual labor, it should be borne in mind that all chemical work requires care and accuracy, and in these respects boys are naturally a source of concern to the responsible chemist. Moreover, the cheapness of child-labor is largely offset by the increase in the expense-account of laboratory materials, caused chiefly by breakages resulting from carelessness.

Having been authorized by the Anaconda Copper Mining

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* Revised proof not received in time for publication in vol. xxxv. of the *Transactions* (see *Trans.*, xxxv., p. xlv).

Co. to build a new laboratory in Baltimore, Md., I decided to make its equipment superior to any that I had seen in this country or abroad. As in many others, the bulk of the work done in the works-laboratory of our company consists in the routine of a few methods applied to many determinations. At Baltimore the value is determined of the copper, silver and gold contained in the crude material that is handled in the works. This analytical work is commonly called assaying,—an old and useful art which, however, is too often lightly considered by those having an excessive knowledge of chemistry and metallurgy.

General Arrangement of Laboratory.

Concerning the general arrangement of the laboratory, but little need be said. Mr. Charles H. White, in a paper entitled The Equipment of a Laboratory for Metallurgical Chemistry in a Technical School,[1] which was read at the Atlantic City Meeting of the Institute, February, 1904, has pointed out the desirability of arranging a laboratory in a technical school in such a manner that the greatest amount of work can be done by each student. This systematic arrangement is equally desirable in the works-laboratory, and the one under consideration has been so designed that the number of movements required from the beginning to the end of every operation has been reduced to a minimum.

The hygienic arrangements of the room should also be given proper attention, especially the ventilation, which as a rule is only made satisfactory by the proper construction of the hoods. At our new works-laboratory the two-compartment brick hood is plastered on the inside and has a tile floor, the openings into the laboratory being supplied with vertical sliding glass doors. The stack, 21 ft. high, is directly over the slate roof of the hood, which tapers from two sides toward the openings of the stack. The cross-section of the openings from the hood to the stack equals that of the free space in the stack. The hood is built against the wall of the building, and parallel to this wall is a second one, leaving a free space of 4 in. between them which communicates with the hood by a number of 2- by 4-in. holes,

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[1] *Trans.*, xxxv., 117.

along the floor, and with the stack by a larger opening at the highest point of the hood. This construction gives a good draught along the floor, as well as at the apex of the hood, and, regardless of the amount of copper that is being dissolved with nitric acid, there is never any noxious odor of "red fumes" in the work-room of our laboratory. A plan and part section of the new laboratory of the Anaconda Copper Mining Co. at Baltimore, Md., are given in Figs. 1 and 2 respectively.

With regard to cleanliness of work in the laboratory, my first teacher in practical chemistry, Hermann von Fehling, used to tell his students, that "*Der Chemiker muss im Frack-Anzug arbeiten koennen.*" This remark made a lasting impression upon me, and I have always disliked the sight of black or yellow hands, or of work-clothes having many spots and holes. It is not given to everyone, however, to be as tidy as Fehling was, but it is possible to aid natural defects by artificial means.

Conveniences for Handling Beakers and Acids.

As already stated, assaying forms the bulk of the work at the Baltimore laboratory. Scores of silver-determinations and hundreds of scorifications and cupellations for gold are often made. Silver, and sometimes gold, is determined in the metallic copper-material by what is commonly known as the combination method, which consists in dissolving both copper and the contained silver in nitric acid, leaving the gold as a metallic residue. The silver is re-precipitated in the form of chloride and, with the gold, is separated from the copper solution by filtration. The incineration of the filter, scorification with metallic lead, and cupellation with a subsequent parting of the two precious metals, completes the assay. We have simplified this operation first by the introduction of metallic trays to hold the No. 5 Griffin beakers, thus avoiding handling them either singly or in pairs. Each tray, shown in Fig. 3, holds nine beakers, and, as soon as the copper has been dissolved, the tray may be placed directly on the fire in order to expel the nitrous fumes by boiling the solutions. The acid used to dissolve the copper is kept in a 5-gal. bottle, having a glass cock, or spigot, with a 0.25-in. orifice, through which the outflow is very rapid. From this bottle the acid is tapped into a specially designed measuring-cylinder shown in Fig. 4, provided with a stop-cock similar to that

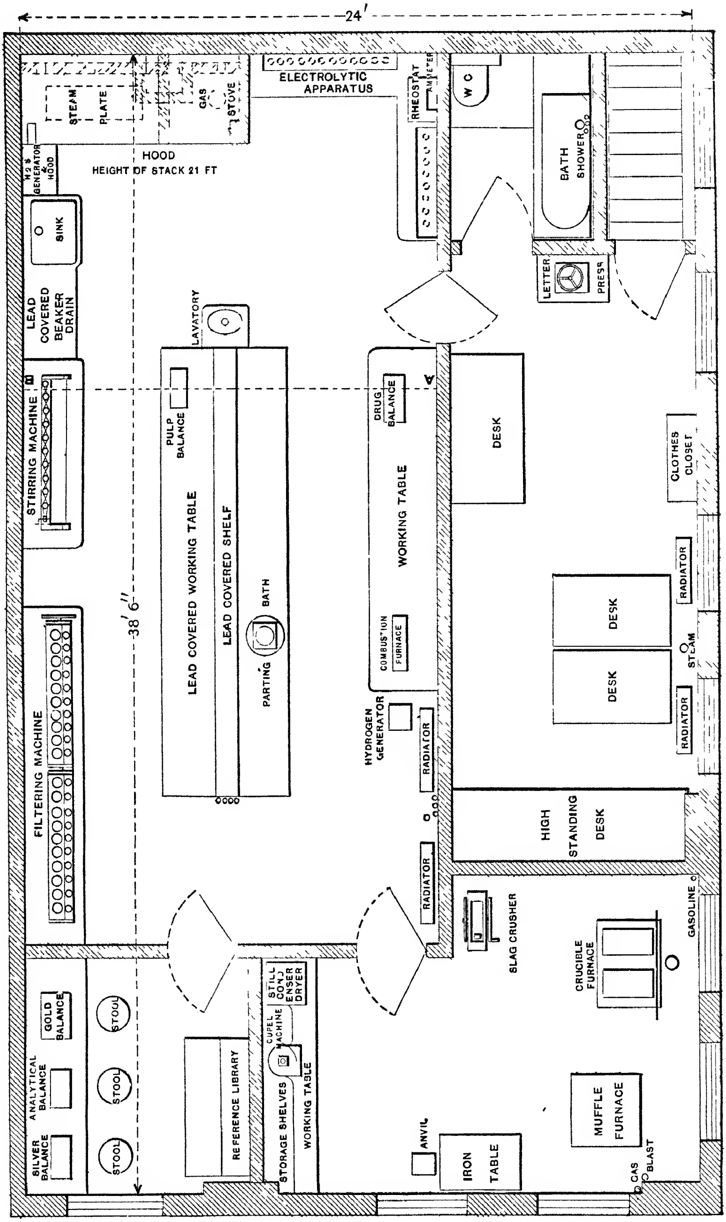


Fig. 1 —Plan of the New Laboratory of the Anaconda Copper Mining Co at Baltimore, Md.

of the bottle, which allows the acid to be tapped into the beakers, without dripping, in a neater and cleaner manner than can be done by pouring from a bottle, beaker or cylinder.

After the copper solutions have become cold and the proper quantity of sodium chloride requisite to precipitate all the silver has been added, it is absolutely necessary to stir the mixture in order that the reaction shall take place throughout, and that, after adequate settling, none of the silver chloride will run

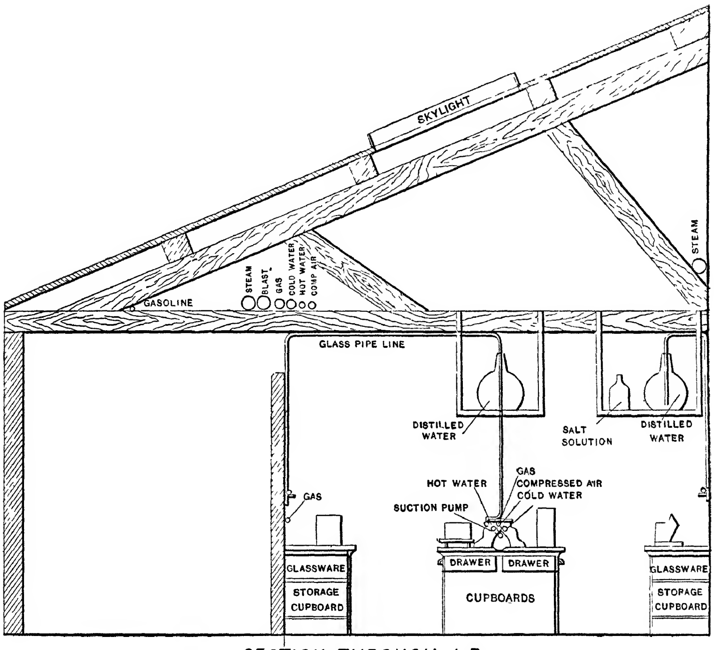


FIG. 2.—SECTION THROUGH PART OF THE NEW LABORATORY OF THE ANACONDA COPPER MINING CO AT BALTIMORE, MD

through the paper during the subsequent filtration. The stirring of a large number of solutions by hand occupies much time and is very tedious, but omitted, the determination becomes faulty. Figs. 5, 6 and 7 illustrate a stirring-machine which obviates all the difficulties incident to the manual operation of stirring and, by its use ten solutions can be stirred in the same length of time occupied in stirring one by hand, and there is no splashing of solution or breakage of beakers.

Fig. 5 shows the machine ready for use; Fig. 6 shows the position after the stirring-rods have been lifted from the solutions and are ready to be rinsed; and Fig. 7, the position assumed after the rods have been rubbed off, the disks holding them and forming a cover to the beakers, now being ready to be washed. This latter operation, however, is generally superfluous, for very seldom does any of the solution reach the covers.

The characteristics of this stirring-machine are the three-based feet; the convenient driving-gear on the right, which admits of the ready application of mechanical power; the slack take-up for the belt on the left; and the rubber disks which hold the rods and form covers to the beakers. The action of the machine is made universal by having several holes in each disk so that the position of the rods will conform to any size of beaker. The separate construction of both beaker-stand and stirring-stand permits a ready change of a set of beakers and allows the rods to remain a permanent part of the whole. Descriptions of stirring-machines are given in some catalogues of manufacturers of chemical apparatus, but they seem to lack the essentials necessary for successful manipulation.

Filtering-Apparatus.

The construction and operation of the filtering or decanting apparatus are illustrated in Figs. 8, 9 and 10; and by its use 20 filtrations can be performed with perfect ease, and without the least danger of loss by splashing or breakage. The beaker-rack is tilted by means of a hand-wheel on the right, retrograde motion being prevented by a ratchet. The point of rotation of the whole series of beakers lies some distance from their lips, about at the end of the glass rods that guide the stream of liquid to a definite point in the filter, an arrangement which is essential for steady pouring. The lifting of the load is aided by a counterpoise on the left. By the use of this apparatus the filtering can be done leisurely with one hand, so steadily that the precipitate remains undisturbed until all the clear liquid is poured off, and the time of the whole operation is greatly shortened. Figs. 8 and 9 show the machine as originally constructed, with a locking-device for each beaker and rod, consisting of an arm pressed downward by a spring, and free to rotate vertically within an angle sufficient to clamp, as

well as to allow it to sweep horizontally over the rod and beaker, the horizontal rotation also being entirely free. Fig. 10 presents a locking-device on the same machine by means of which ten beakers and rods are locked simultaneously. It is a matter of taste which arrangement is the more satisfactory. The beaker-rack and the filter-stand are adjustable to several sizes of beakers and funnels, and the machine can be made for any number of beakers. Light wooden trays are provided to carry the beakers, in sets of ten, to and from the apparatus.

Table I., containing the results of a test recorded by one of my assistants, shows the difference in time between the new method of mechanical filtration and the old method by hand. Twenty beakers, each containing between 275 and 300 c.c. of solution, were used in the test.

TABLE I.—*Comparison of Results of Machine-Filtration vs. Hand-Filtration* (20 *Beakers*).

Machine-Filtration			Hand-Filtration		
		Time Consumed Minutes			Time Consumed. Minutes
10.21 a.m.	Started		11 13 a.m	Started.	
10 22 a.m.	Placed rods	1	11.14 a m.	Placed rods	1
10 30 a.m.	Finished decanting .	8	11 38 a.m.	Finished decanting .	24
10.41 a.m.	Washed beakers and rods	11	11.58 a.m	Washed beakers and rods	20
10.45 a.m.	Washed filters..	4	12.04 p.m.	Washed filters	6
10 55 a.m.	Rubbed out beakers.	10	12.13 p m	Rubbed out beakers.....	9
10 59 a.m.	Folded filters and placed in scorifiers..	4	12.17 p.m.	Folded filters and placed in scorifiers. .	4
Total	....	38	Total	.. . .	64
Difference in favor of machine, 26 minutes					

I have decanted ten beakers, each containing from 275 to 300 c.c. of solution in 4 min. 30 sec., the solutions being run through a double S. & S., No. 597, 12.5-cm. filter.

In connection with the work just described, we have entirely dispensed with the well-known wash-bottle, on account of the unnecessary physical strain involved in its use, as well as its unsanitary character in many instances. The distilled water, contained in carboys placed about 4.5 ft. above the floor-level, is siphoned into a system of glass-tubing, extending throughout the laboratory wherever the water may be needed. This glass-tubing is provided with numerous T-connections to

which are attached rubber-tubes, having pinch-cocks and glass nozzles at their ends, which permit the direction of a stream of water to any desired point. The water in the overhead carboys is replenished by forcing up through a glass tube, by means of compressed air, a new supply from another carboy (in which it has been condensed) placed on a carriage on the floor.

When the filtration is complete and the precipitates have been washed out of the beakers, the latter must be rubbed out with paper in order to be sure that neither silver chloride nor gold is retained on the walls of the vessels, perhaps by a little oil often contained in the samples, or by the drying and hardening of small particles of chloride above the surface of the solution. In order to facilitate this cleansing, we have designed a machine in which the beakers are rotated. This machine is on rollers, and runs on rails fastened to the table in front of the filtering-apparatus, and may be locked at any desired point. The cleansing is done by means of a "policeman," Fig. 11, which consists of a rod having a cork fastened at one end, over which is clamped a piece of filter-paper, held in place by a conically-cut ring. The paper thus fastened is rubbed along the bottom and sides of the rotating beaker. For each beaker a fresh piece of paper is quickly clamped to the cork.

New Assay-Furnace Tools.

The implements used in performing the furnace-work in assaying are shown in Fig. 12. *A* and *B* are the traditional tongs, universally used for handling singly the scorifiers and the cupels. The former has been entirely replaced with a fork, *C*, with which a set of 20 scorifiers can be handled at one time. In silver-assaying each set of scorifiers is placed in the muffle twice and taken out twice; first, put in the muffle for the incineration of the filters, then taken out for the addition of the test-lead, then returned for scorification, and finally taken out for pouring the slag and molten lead into the molds. By the use of the fork, which works perfectly if the muffle be properly supported so that it will not sag to any marked extent, 60 handlings are reduced to three. Four scorifiers constituting a longitudinal row in the muffle are poured at one time by means of a pair of tongs, *D*, and with a little practice the pouring is made just as easy as with a single scorifier. It is neces-

sary only that the molds correspond to the arrangement of the scorifiers and that the pockets are shallow. The cupels are placed into, or taken from, the muffle in sets of one or more rows, by means of the tools, *E*, *F* and *G*., an idea which, I believe, was first put into practice by my brother, Richard Keller, of Durango, Colo. *E* and *G* are sharp-edged shovels, the latter having upturned sides. *F* is a rabble, with which the cupels are raked onto the shovel, and removed thence to the place where they are to be deposited by placing it behind them and withdrawing the shovel. The tool, *H* and *I*, is entirely new, and by its use, one or more rows of cupels in the muffle may be charged with the lead-buttons from the scorifiers. Fig. 13 shows the idea of the device more clearly. It comprises a top sliding-plate with openings corresponding exactly to the position of the cupels. The openings in the lower plate correspond exactly with those of the upper one; the plate, however, rests on two adjacent sides extended downward at right-angles to the plate and to each other, thus forming two closed sides of the instrument; one at the front, and the other at the right-hand side. The height of these sides is such that, when resting on the bottom of the muffle, the bottom plate will be some distance above the cupels and, by a slight pull forward and a push to the left with the handle of the instrument, the set of cupels will be perfectly aligned in both directions, and the apertures in the lower plate will exactly cover the tops of the cupels. The lead-buttons are placed in the apertures of the upper plate and rest on the lower plate before introducing the instrument into the furnace, and when it is placed over the cupels, which have been properly aligned in the muffle, the upper plate is pushed forward to a stop-point, bringing the apertures of the two plates to register, thus causing the lead-buttons to drop down into the cupels. The handle of the upper plate runs through guides fixed to the handle of the lower plate; both handles are connected with a spring, which acts as a brake when the upper plate is pushed forward to drop the buttons, and also serves to bring it back into its original position, in which the buttons cannot drop through the apertures in the lower plate.

Charles Tookey[2] first recommended the use of hydrochloric

[2] *Journal of the Chemical Society* (London), vol. xxiii., p. 366 (1870).

acid (1 HCl.aq, 2 H_2O) instead of a brush for cleaning the buttons, and for this purpose a small silver dish and tray having perforated pockets give excellent satisfaction. By the use of this device 50 or more beads at a time can be treated, washed and dried without transfer.

Fig. 14 shows a very handy parting-bath; which though old in principle has not been in general use. The vessel is a constant-level water-bath and the tray an ordinary test-tube holder. The silver beads to be parted are dropped into the test-tubes, and the latter filled with dilute nitric acid of a strength of one of acid (sp. gr. 1.42) to 9 of water. The water in the bath is first brought to the boiling-point before the tray with its contents is set into it. Treated in this way, the gold almost invariably remains in the form of a small coherent bead, even from an alloy as low as 1 part of gold to 500 of silver.

I have recognized that the system of handling everything in sets was incomplete as long as I was unable to take a whole set (20) of scorifiers from the muffle and pour their contents simultaneously into the molds. Recently a tool for that purpose, shown in Figs. 15 and 16, has been perfected. It is composed of quintuple tongs, corresponding to the five longitudinal rows of scorifiers in the muffle. The lower part of each pair of the tongs consists of a fork, on which the scorifiers rest, and one of whose prongs is rectilinearly extended through two bearings in a frame, and held in position by collars. This extension is free to revolve in the bearings, and forms the axis of rotation of the tongs. To each of them is attached, at right angle, a lever, extending upward at an angle of 45°, and all the levers are connected by slotted joints to a cross-rod. Therefore, if by means of a crank, fastened to the end of one of the extended prongs, one of the forks is turned and the scorifiers tilted to the desired angle, the others perform the same rotation. The center of gravity of the scorifiers lies to one side of the rotation-point, and they would therefore, on being lifted, tilt in that direction; this motion, however, is prevented by the cross-bar resting against a post at that end of the frame toward which the inclination tends.

The scorifiers are clutched by the upper prong of the tongs, which is fastened to a spring on a post of the fork below, and which is free to move in a vertical plane; the pivotal point

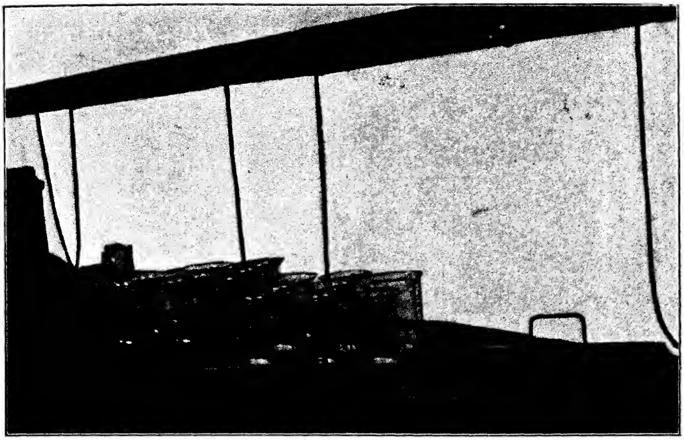


Fig. 3.—Metallic Trays Holding Nine No. 5 Griffin Beakers.

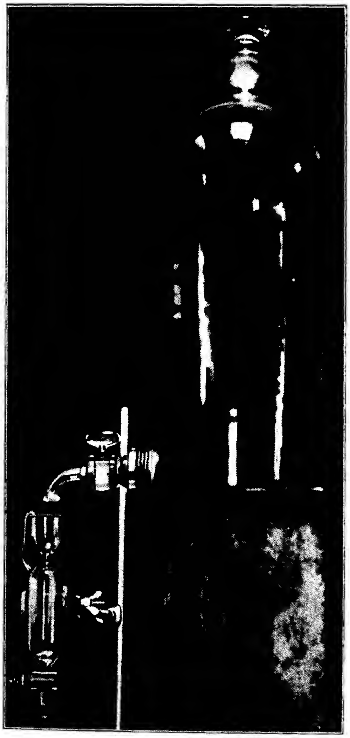


Fig. 4.—Cylinder for Measuring Acid.

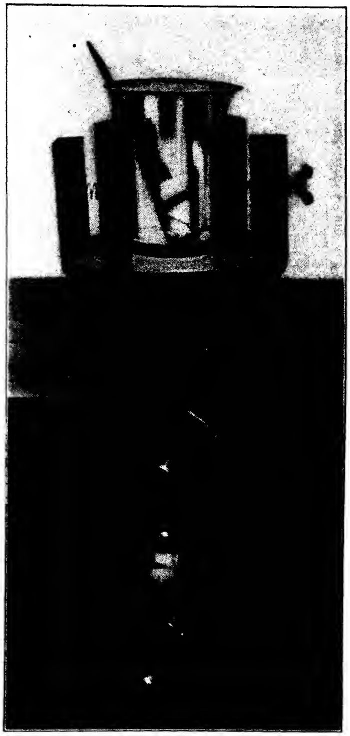


Fig. 11.—The "Policeman" in Beaker on Rotating-Machine.

[To face p. 12.]

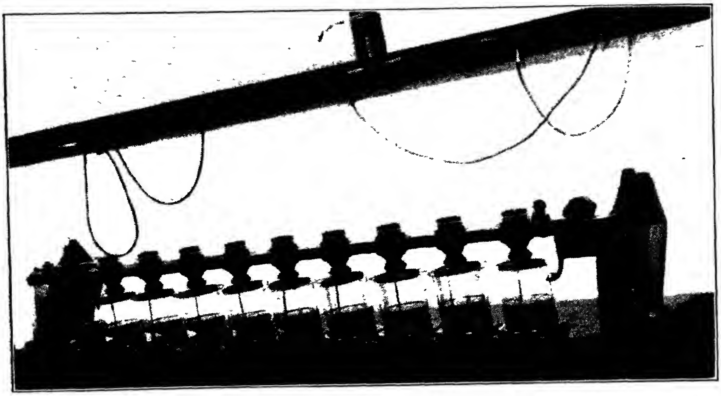


Fig. 5 —In position ready for use.

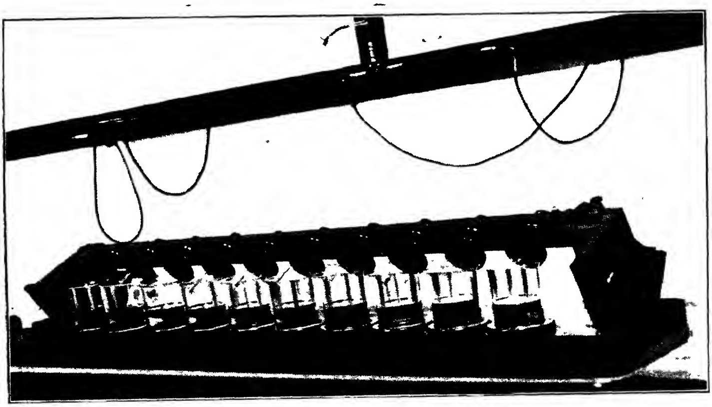


Fig. 6.—In position ready for rinsing, after lifting out the stirring-rods.

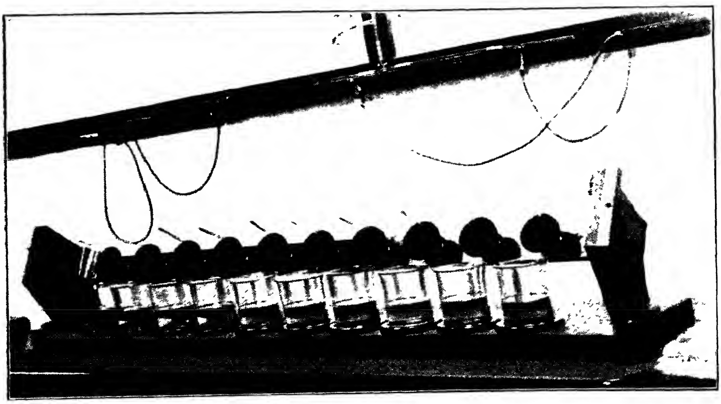


Fig. 7.—In position ready for washing off the disks.

The Stirring-Machine.

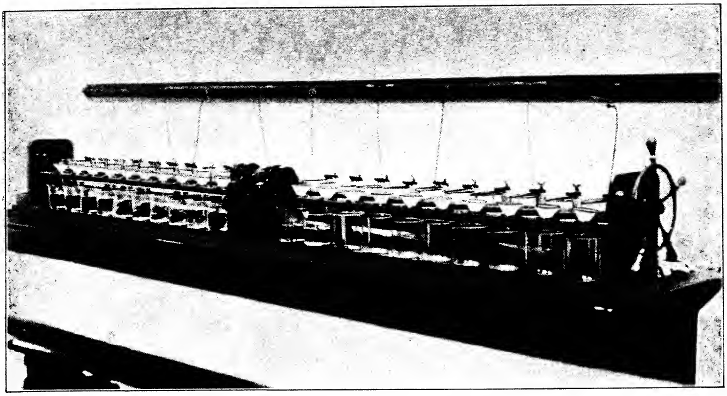


Fig. 8.—Original machine, ready to begin Filtration or Decantation.

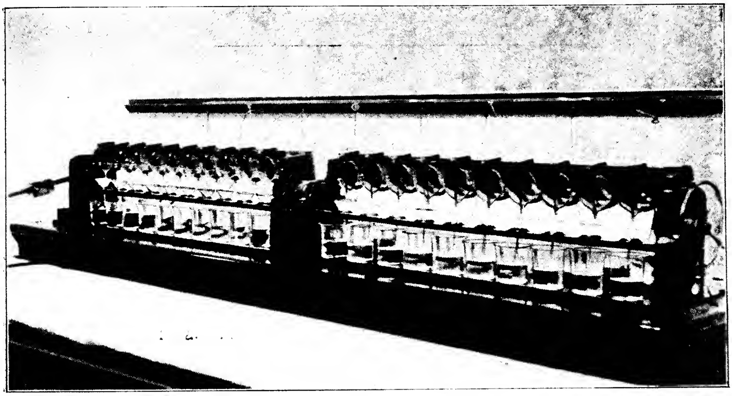


Fig. 9.—Original machine, position at end of filtration.

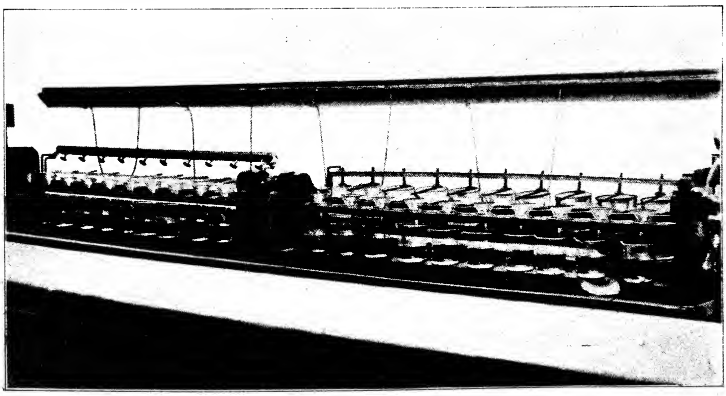


Fig. 10.—Original machine with new multiple locking-device.

The Filtering- or Decanting-Apparatus.

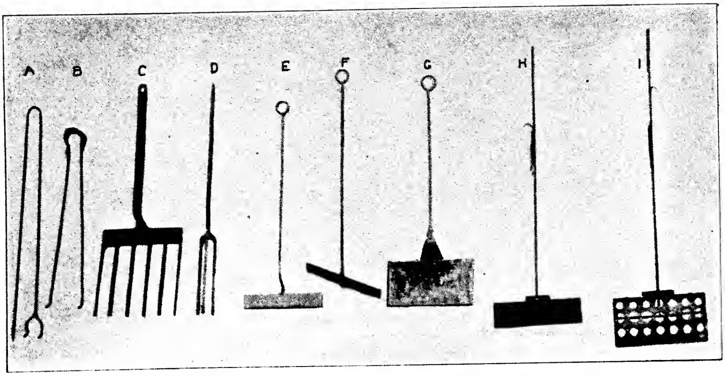


FIG. 12.—ASSAY FURNACE TOOLS.

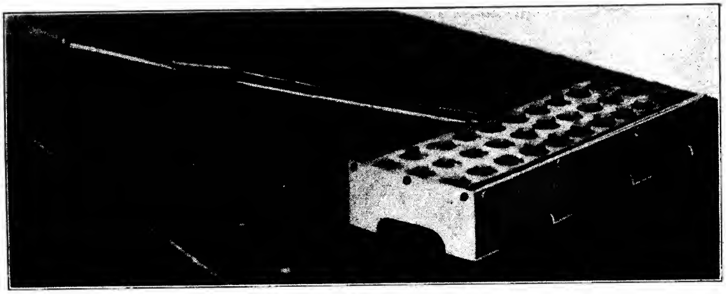


FIG. 13.—DEVICE FOR CHARGING SCORIFIER BUTTONS ONTO CUPELS.

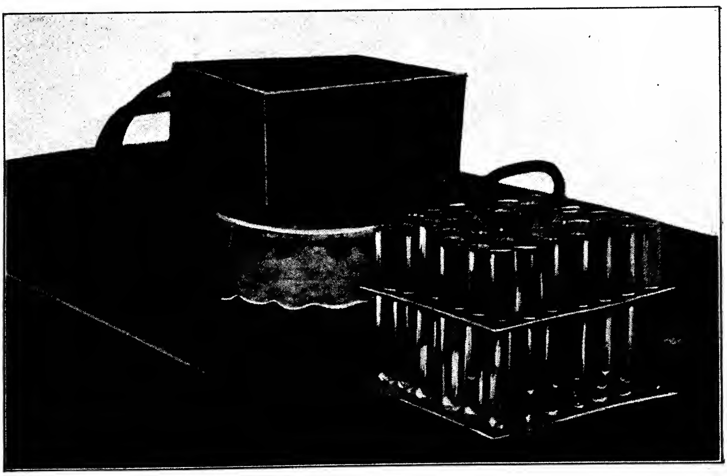


FIG. 14.—CONVENIENT PARTING-BATH.

[To face p. 17.]

lying over the spring and post. By bringing pressure on the extended ends of these clutch-bars behind the pivot, their other end will rise from above the scorifiers, and thus release them, or permit the placing of them onto the tongs. The pressure exerted on the rear ends of the clutches is accomplished by means of a cross-bar fastened to a spring-bar, which is itself

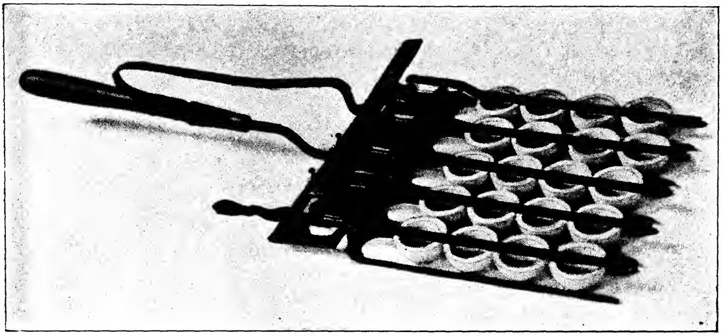


Fig. 15.—Multiple Tongs; Scorifiers in Position for Removal from Furnace.

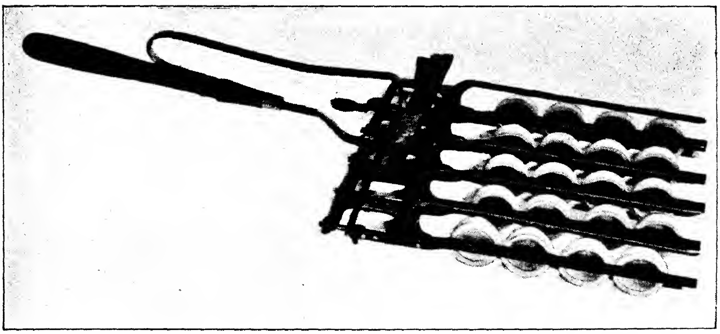


Fig. 16.—Multiple Tongs; Scorifiers Tipped for Pouring Contents.

riveted to the handle of the instrument. These details are plainly shown in Figs. 15 and 16. In pouring the contents of the scorifiers, the frame of the tool rests on the edge of the mold, leaving the tongs free to turn.

The introduction of the new system of manipulation described in this paper has resulted in economy in several ways. Much labor has been saved; breakage of expensive glass-ware

has been very largely eliminated; and the time of the furnace-work, and, consequently, the consumption of gas, have been much reduced. Furthermore, the gain has been a moral one, and work formerly regarded as tedious has become more of a pleasure; especially since the sojourn in the furnace-room during the hot summer months has been rendered cooler by being greatly shortened.

The appliances described in this paper may eliminate the laboratory-boy, but if not, they will make him more reliable. They also increase enormously the quantity of chemical work that one man can do in a day. In the small domain of our laboratory the change from the old systems to the new is considered to bear about the same relation as the change from the ancient horse-car to the modern rapid transit.

In conclusion, I take pleasure in acknowledging the efficient collaboration of my assistants, Mr. Albert Ferrell and Mr. K. W. McComas, the former having shown himself particularly useful as a skilled mechanic in the construction of the various improvements.

The Effect of Impurities on the Electrical Conductivity of Copper.

BY LAWRENCE ADDICKS, PERTH AMBOY, N J

(Washington Meeting, May, 1905.)

ONE of the properties of copper, which has done much to give it its present prominent place among the useful metals, is its electrical conductivity,—a property which has now become the chief criterion of the value of the commerical product. In pursuance of that distinctively American principle that, "the best is none too good," metal of the highest conductivity is usually called for even when such extreme purity is of no advantage; for instance, in the making of brass and other alloys. The average brass-founder feels nervous unless his copper is so very pure that it shows a conductivity of 99 or 100 per cent., while the character of the zinc used is usually overlooked in his anxiety.

Electrolytic refining has made it possible to produce copper

of a very high degree of purity, the metallic impurities averaging but a few thousandths of 1 per cent.; oxygen, usually present in the form of cuprous oxide, bringing the total up to about a tenth of 1 per cent. The published data bearing upon the relationship between chemical purity and electrical conductivity is, however, very scant,[1] nearly all the work that has been done having dealt with alloys carrying considerable quantities of the foreign elements. In this paper I have brought together the results of experiments extending over a period of several years, that have been carried out with the idea of determining the amount of various elements which would lower the conductivity 3 or 4 per cent.—a series of impure coppers rather than alloys.

There are many precautions necessary to keep the conditions identical in different experiments, since molten copper is very sensitive chemically to its surroundings and the quantity of many substances required to lower its conductivity several per cent., is exceedingly minute. The method of procedure adopted after considerable experimenting was as follows:—

The copper used was in the form of No. 12 B. & S. annealed wire, compacted together and placed in a round Battersea crucible, size H, 500 g. constituting a charge. The impurity was added in one of three ways, depending upon its melting-point,— 1. If high, it was dumped in a weighed amount directly into the bottom of the crucible. 2. If comparatively low, some of the copper wire was rolled out into foil and the impurity encased in it, the whole being put at the bottom of the crucible; and 3. If very low (such as phosphorus), it was wrapped in foil as before, but thrust under the surface of the molten copper just before pouring the samples. After the wire was rammed home in the crucible, a layer of broken charcoal about an inch thick was placed on top, the whole filling the crucible. A lid was put on the crucible which was then subjected to a strong blast in a gas-furnace. The sample was poured 25 min. after turning on the blast, which was just sufficient time to melt the charge thoroughly without over-heating it, and not appreciably alter the "pitch" of the copper. No trouble was experienced in

[1] Matthiessen, in *British Association Reports*, 1862–4 Also table of alloys exhibited by Mouchel at the Paris Exposition of 1889, reported by Hering, *Electrical Engineer*, N. Y., ix., p. 344.

getting elements much below their melting-points at this heat to dissolve in the molten copper. Castings were made in a heated iron mold in the shape of slightly tapering cylinders having an average diameter of 0.5 in. and a length of 7 inches. These castings were swaged hot on an anvil to $\frac{3}{8}$ in. in diameter and then drawn cold to No. 12 B. & S. wire. Then, in order to eliminate the effects of the drawing, the wires were annealed electrically by forcing them to carry a current of 110 amperes. The electric method of annealing is a very simple way of accurately duplicating results, the temperature of annealing having a marked influence on the conductivity.[2] The wires were measured for conductivity and then analyzed for copper and the foreign element. The sum of the copper plus the impurity was a general check on the analysis and the "pitch."

Table I. gives a general summary of the data, the elements being arranged alphabetically. The data are also expressed graphically in Figs. 1 to 16. The alloying elements were obtained in as pure a form as possible, and it is not believed that the results are greatly influenced by impurities in them. These were,—proof-silver 1,000 fine; gold in the form of prills from bullion-analyses carrying no impurity, but a negligible amount of silver; test-lead; electrolytic iron free from carbon; and sulphur as cupric sulphide. The other elements were of the chemically pure (C. P.) grade obtainable in the market.

In examining the results it is natural to group the elements in their order in the periodic system. This is done in Table II. The column headed "factor" gives the ratio of the lowering of the conductivity, to the amount of the impurity present. In obtaining this ratio, tangents to the curves in Figs. 1 to 16 have been used, so that the ratios hold strictly true only in the case of an infinitely small lowering. The factor is seen to bear a general relation to the periodic arrangement, decreasing with increasing atomic weight within any one group, though there is no evident relation between one group and another. This factor is of use when examining the analysis of a copper which shows low conductivity, as a means of indicating the probable cause of the trouble. The data do not yield even an approximate constant for molecular lowering of the conductivity—that

[2] Addicks, *Transactions American Institute of Electrical Engineers*, xxii., p. 695 *et seq.*

TABLE I.—*Summary of Data.*

Element Added	1st Sample			2d Sample			3d Sample			4th Sample		
	Added	Cu	Cond	Added	Cu	Cond	Added	Cu	Cond	Added.	Cu	Cond.
	Per Cent	Per Ct	Per Cent	Per Cent	Per Ct	Per Cent	Per Cent	Per Ct	Per Cent	Per Cent	Per Ct	Per Cent.
Aluminum	0	99 96	99 6	0 006	99 90	98 6	0 109	99 65	66 8	0 739	99 03	43 5
Antimony	0 007	99 96	99 6	0 022	99 94	97 2	0 047	99 86	95 4			
Arsenic	0 004	99 96	99 6	0 007	99 95	96 8	0 013	99 94	93 2	0 140	99 82	62 3
Bismuth	0	99 96	99 6	0 028	99 93	99 6	0 045	99 91	99 3			
Cadmium	0	99 96	99 6	0 062	99 90	99 5	0 113	99 87	99 1	0 427	99 55	96 1
Gold	0	99 96	99 6	0 089	99 86	98 9	0 149	99 84	98 4	0 317	99 64	96 4
Iron	0	99 89	100 5	0 042	99 93	96 8	0 046	99 90	92 9	0 068	99 89	89 6
Lead	0	99 96	99 6	0 083	99 82	99 1	0 052	99 86	98 7	0 347	99 56	98 3
Oxygen	0 020	99 98	100 7	0 050	99 95	101 4	0 100	99 90	100 5	0 200	99 80	98 0
Phosphorus	0	99 96	99 6	0 080		52 3						
Silicon	0	99 96	99 6	0 007	99 89	99 4	0 007	99 89	99 1	0 042	99 89	99 0
Silver	0 003	99 89	100 5	0 137	99 81	100 0	0 340	99 60	98 3	0 503	99 49	97 9
Sulphur.	0	99 89	100 5	0 053	99 93	100 0	0 135	99 83	99 0	0 236	99 75	98 9
Tellurium	0	99 89	100 5	0 065	99 82	100 4	0 181	99 74	100 2	0 405	99 65	98 7
Tin	0	99 96	99 6	0 052	99 85	97 6	0 097	99 85	92 7	0 295	99 61	79 8
Zinc	0	99 96	99 6	0 048	99 91	98 3	0 095	99 79	96 3			

TABLE II.—*Factor* $= \dfrac{\textit{Percentage Lowering in Conductivity.}}{\textit{Percentage Impurity Added.}}$

Periodic Group	Element Added	Factor	Atomic Weight	Remarks
I	Silver	6	108	
I	Gold	10	197	
II	Zinc	30	65	
II	Cadmium	9	112	
III .	Aluminum	500	27	
IV	Silicon	70	28	
IV	Tin	67	119	
IV .	Lead	3	207	Made metal red short
V	Phosphorus	3,000	31	
V	Arsenic	720	75	
V	Antimony	190	120	
V	Bismuth	4	208	Made metal red and cold short
VI	Oxygen	25	16	Large amounts made metal brittle
VI	Sulphur	8	32	
VI	Tellurium	4	128	Made metal red and cold short
VIII	Iron	140	56	

is, the "factor" multiplied by the atomic weight—even within single periodic groups.[3]

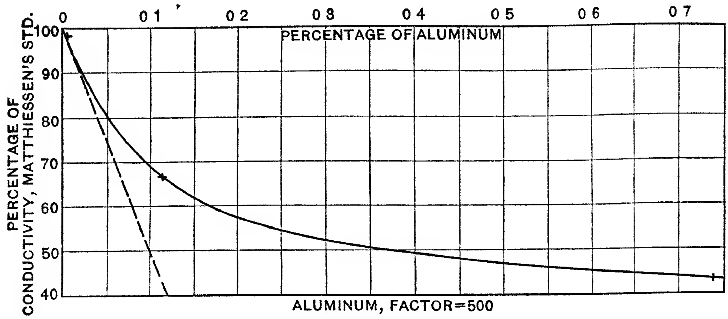
The form of the composition-conductivity curve of a binary alloy may be one of four different types.[4]

1. When the constituents are mutually soluble in all propor-

[3] Cf. Benedicks, *Zeitschrift fuer Physikalische Chemie*, xl., p. 545.

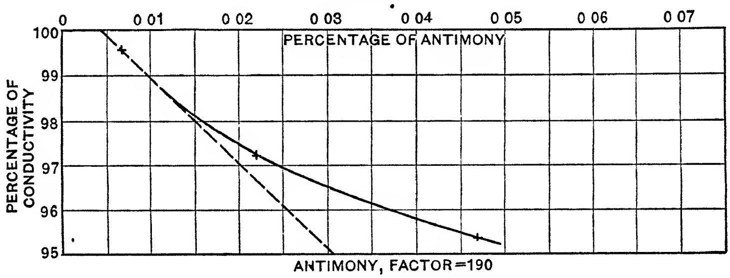
[4] Howe, *Iron, Steel and Other Alloys*, pp 154 to 159.

FIG. 1.



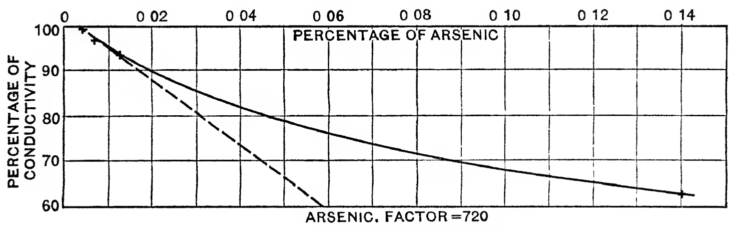
EFFECT OF ALUMINUM ON ELECTRICAL CONDUCTIVITY OF COPPER.

FIG. 2.



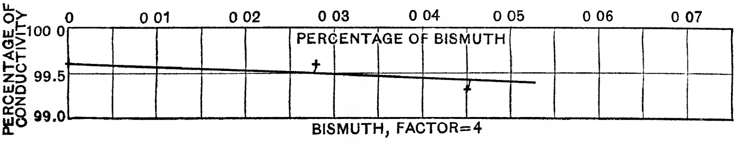
EFFECT OF ANTIMONY ON ELECTRICAL CONDUCTIVITY OF COPPER.

FIG. 3.



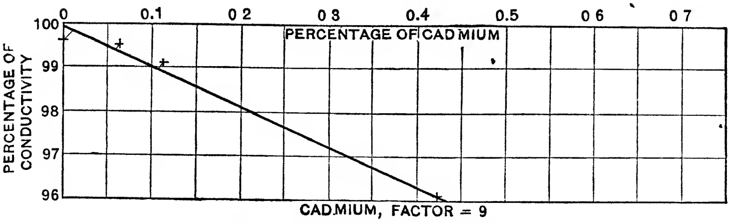
EFFECT OF ARSENIC ON ELECTRICAL CONDUCTIVITY OF COPPER.

FIG. 4



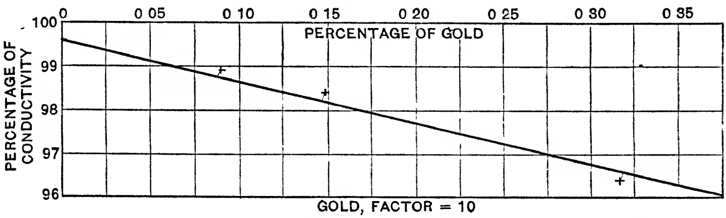
EFFECT OF BISMUTH ON ELECTRICAL CONDUCTIVITY OF COPPER.

FIG. 5.



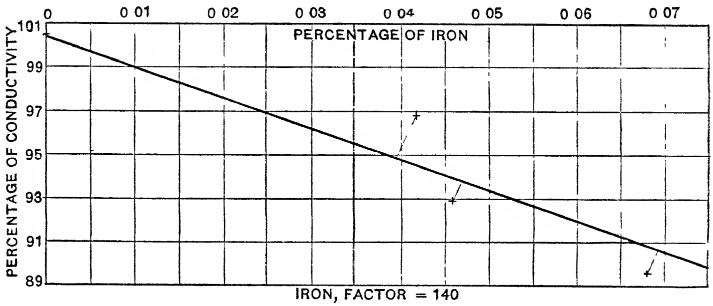
EFFECT OF CADMIUM ON ELECTRICAL CONDUCTIVITY OF COPPER.

FIG. 6.



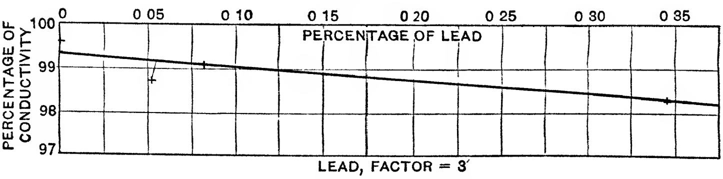
EFFECT OF GOLD ON ELECTRICAL CONDUCTIVITY OF COPPER.

FIG 7



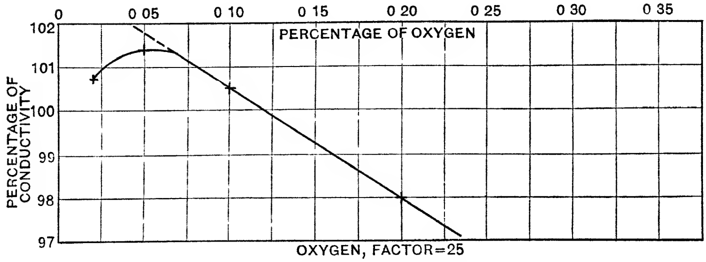
EFFECT OF IRON ON ELECTRICAL CONDUCTIVITY OF COPPER

FIG. 8.



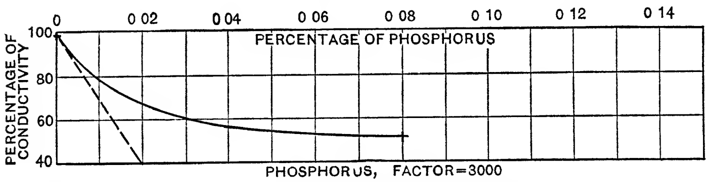
EFFECT OF LEAD ON ELECTRICAL CONDUCTIVITY OF COPPER.

FIG. 9.



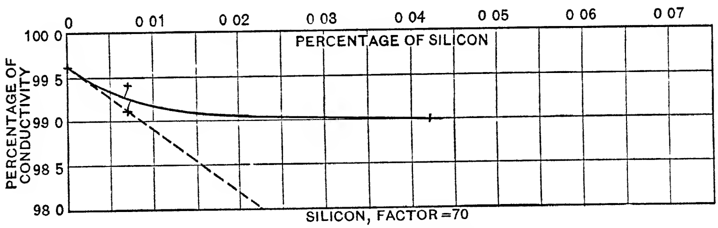
EFFECT OF OXYGEN ON ELECTRICAL CONDUCTIVITY OF COPPER.

FIG. 10.



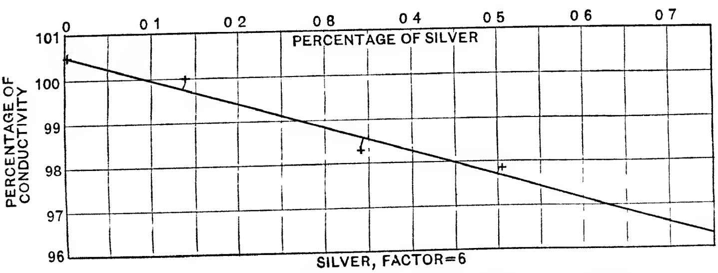
EFFECT OF PHOSPHORUS ON ELECTRICAL CONDUCTIVITY OF COPPER.

FIG. 11.



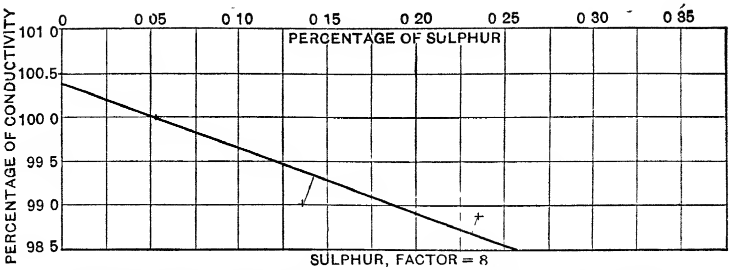
EFFECT OF SILICON ON ELECTRICAL CONDUCTIVITY OF COPPER.

FIG. 12.



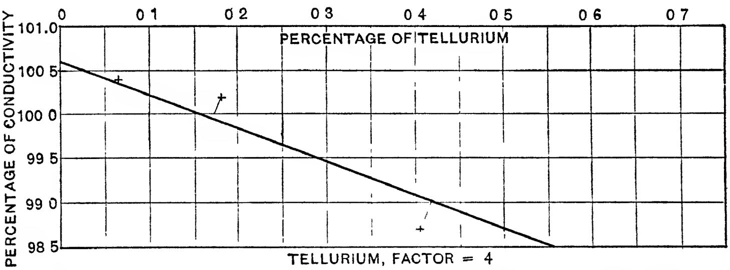
EFFECT OF SILVER ON ELECTRICAL CONDUCTIVITY OF COPPER.

FIG. 13.



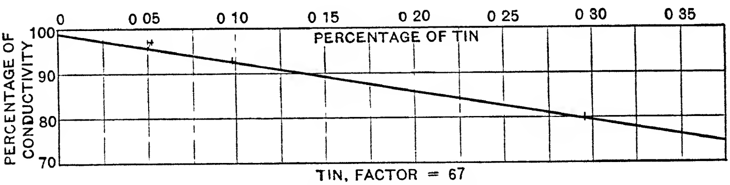
EFFECT OF SULPHUR ON ELECTRICAL CONDUCTIVITY OF COPPER.

FIG. 14.



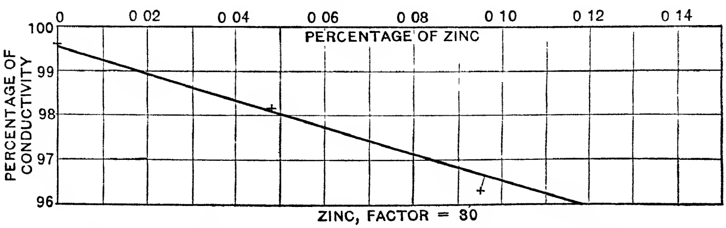
EFFECT OF TELLURIUM ON ELECTRICAL CONDUCTIVITY OF COPPER.

FIG. 15.



EFFECT OF TIN ON ELECTRICAL CONDUCTIVITY OF COPPER

FIG. 16.



EFFECT OF ZINC ON ELECTRICAL CONDUCTIVITY OF COPPER.

tions. The composition-conductivity plot of such a case gives a smooth curve throughout.

2. When the constituents are mutually insoluble in any proportions, in which case the conductivity-curve becomes a straight line, the so-called alloy being but a mechanical mixture.

3. When the mutual solubility is limited, there is a soluble series at each end of the curve and a eutectiferous series in the middle. Since two substances absolutely insoluble in one another probably do not exist, case 2 cannot be rigidly applied, such substances forming an extreme application of case 3.

4. Lastly, there are cases where definite chemical compounds are formed, which may give a curve with a soluble series at one end and a wholly eutectiferous series at the other.

The results given in this paper deal entirely with the first very short part of the conductivity-curve, and it therefore should be expected that some curvature would be shown in every case. Some of the elements employed are so nearly insoluble in copper, however, that the curve differs but little from a straight line connecting the conductivities of the two pure substances in the mixture.

The useful alloys of copper comprise mixtures with zinc, tin, aluminum, silicon and phosphorus Zinc and tin are added in relatively large quantities to form brasses and bronzes. Aluminum, silicon and phosphorus are added in comparatively small quantities and their ability to deoxidize copper that has been needlessly exposed to the air in melting, probably comes much more frequently into play when making castings than the founder imagines. Under proper conditions it is perfectly possible to make copper-castings of perfect soundness and conductivity, without the use of fluxes. But, looking at the table of factors, it is seen that no worse elements could have been picked out from an electrical standpoint than those above mentioned. On the other hand, the elements which have but little effect upon the electrical conductivity—lead, bismuth and tellurium—make the metal extremely brittle. This effect seems to be a question of solubility, the last-named elements being practically insoluble in copper. We then have a mechanical mixture in which the conductivity is only affected in accordance with the proportions of the mixture, while the mechanical properties of the foreign element itself are brought into prominence.

With the other classes of substances a very different state of affairs exists, the alloy being copper embedded in a matrix of an alloy of copper and the impurity. The conductivity of this matrix is, in general, low, and its amount is beyond all proportion to that of the impurity added, and hence the magnified depression of the conductivity of the whole. Metallographic work with the microscope bears this out; 0.1 per cent. of bismuth, for example, causing but a thin skin around the copper crystals, while the same amount of arsenic forms a thick wall.[5] It is often possible to counteract the detrimental mechanical effects of one impurity by adding another, as in the case where a relatively innocuous impurity may dissolve an otherwise insoluble one, like lead.[6]

The results given in Table I. show what a severe requirement the customary 97- or 98-per cent. conductivity-specification is, especially as copper is usually associated with arsenic; and when it is considered that the average electrolytic refinery daily passes this requirement by a margin of 2 or 3 per cent., frequently using anodes containing 1 per cent. or more of arsenic, it will be appreciated that electrolysis would have come as a refining operation even did copper never carry gold or silver.

The Occurrence of Stibnite at Steamboat Springs, Nevada.

BY WALDEMAR LINDGREN, WASHINGTON, D. C.*

(Washington Meeting, May, 1905.)

THE important investigations of Dr. G. F. Becker at Steamboat Springs, Nev., in 1885, aided by the analytical work of W. H. Melville, established the fact that sulphides were being deposited at the surface by hot ascending waters.[1] Steamboat Springs is situated near the eastern base of the escarpment of the Sierra Nevada, six miles distant from the Comstock lode.

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[5] Arnold and Jefferson, *Engineering* (London), February 7, 1896.

[6] Lewis, *Engineering* (London), December 4, 1903.

* Published by permission of the Director of the U S Geological Survey.

[1] *Monograph XIII., U. S Geological Survey*, pp. 331–353.

In a region of former volcanic activity, hot springs with a temperature of about 80° C. break forth through a fissure in granodiorite, and at the base of a basaltic bluff the waters have deposited a large amount of siliceous and calcareous sinter, some of which is colored red by antimony sulphide. The sinter from one of the springs was analyzed by Mr. Melville,[2] and his results, re-calculated to grams per kilogram, showed:

	Grams per Kilogram
Ferric oxide,	1 0263
Antimonious and arsenious sulphides,	22.9298
Mercuric sulphide,	0 0021
Cupric sulphide,	0.0124
Lead,	0 0211
Gold,	0 0010
Silver,	0 0003

The relative quantities of antimonious and arsenious sulphides are not given in the above analysis, but I believe that the former greatly predominated.

The water of one of the springs was also analyzed by Melville and the re-calculation of this analysis to salts that were possibly present is given in Table I.

TABLE I.—*Possible Composition of the Water of Steamboat Springs, Prior to Oxidation.*[3]

	Grams per 10 Liters
Ferrous carbonate, $FeCO_3$,	0 0029
Magnesium carbonate, $MgCO_3$,	0 0099
Calcic carbonate, $CaCO_3$,	0 1577
Calcic phosphate, $Ca_3P_2O_8$,	0.0137
Potassic chloride, KCl,	1.9735
Lithic sulphate, Li_2SO_4,	0 5650
Sodic chloride, NaCl,	14 1475
Sodic sulphydrate, NaHS,	0 0358
Sodic sulphate, Na_2SO_4,	1 1147
Sodic bicarbonate, $NaHCO_3$,	2.9023
Sodic monocarbonate, Na_2CO_3,	0 4314
Sodic biborate, $Na_2B_4O_7$,	3 1368
Sodic tetrasilicate, $Na_2Si_4O_9$,	3.9090
Sodic sulphantimonide, Na_2SbS_3,	0.0100
Sodic sulpharsenide, Na_2AsS_3,	0.0866
Alumina, Al_2O_3,	0.0025
Sodium-mercury sulphide, HgS, nNa_2S,	trace

[2] *Op. cit*, p. 344 (Sample II).

[3] *Op. cit*, p. 347

The recalculation given in Table I. is, of course, only of very approximate value, since it is not known with certainty in what condition the different acids and bases are present. Moreover, the salts are partly dissociated. Attention should be called to the fact that the water contains far more arsenic than antimony, but during its filtration a red precipitate formed, consisting of arsenic and antimony sulphides,—in what relative amounts the report does not state.

Having assisted Dr. Becker in his examinations in 1885, I naturally felt a strong interest in this locality; and, in 1901, I revisited the place for a few hours, making a few observations which are here recorded.

The flow of water from the springs was found to be greatly reduced, probably on account of clogging of the channel. Several bore-holes had been sunk in order to obtain a better flow, and from these holes fragments of quartz had been brought up which were said to assay high in gold and silver. Of this I know nothing except from hearsay; but, at any rate, these results seem to have stimulated prospecting activity, for a shaft had recently been sunk to a depth of 30 ft. near the railway-station, on the sinter-flat a few hundred feet away from, and about 20 ft. above, Steamboat creek, which is the main drainage-line ot the valley. After sinking 25 ft. through sinter, a loose sandy gravel was struck containing well-washed pebbles of granite and andesite, which carried so great an abundance of hot water as to lead to the suspension of mining operations. The gravel was said to contain small quantities of gold and silver, but I am not prepared to discuss this aspect of the case; moreover, the assays or the material would have no great value regarding the derivation of the gold and silver if found, for they might have been introduced in different ways. A sample of the same or similar material, transmitted to me in the summer of 1904 by Mr. W. H. Weed, was assayed and yielded a trace of gold.

Upon examining the dump, I found that the gravel throughout contained small shining prisms and particles of metallic luster. A generous sample of the material was collected, but further work was delayed, until 1903, when an examination of the sandy part of the gravel showed it to contain a considerable quantity of stibnite, in the form of loose slender prisms of the usual type, up to about 1mm. in length, and usually with-

out terminal faces. The prisms are sometimes bent and often combined in radiating groups, and may be observed adhering to the surface of nearly every pebble of the gravel, both large and small. Some of the larger granite-cobbles, which usually are soft and decomposed, contain bunches of stibnite crystals in cracks and crevices. With the exception of clastic magnetite, the only other metallic mineral found in the gravel is pyrite, which forms loose or intergrown crystals of octahedral form, sometimes combined with the cube. In many cases both pyrite and stibnite have crystallized on the surface of pebbles, the former often being tarnished to a black color. Grains of quartz occur with the pyrite, but they are not clearly crystallized and may be clastic. A black opaline material containing about 1 per cent. of carbon, according to Dr. E. T. Allen, of the U. S. Geological Survey, sometimes adheres to the andesite pebbles.

In order to obtain an idea of quantitative relationships, the sandy part of the gravel was further examined by Dr. E. T. Allen, who found that lead, copper, zinc and mercury were absent, and that the material contained antimony, 0.4, arsenic, 0.067, and sulphur, 1.88 per cent., which corresponds to stibnite (Sb_2S_3), 0.56; orpiment, (As_2S_3), 0.107; and pyrite (FeS_2), 3.13 per cent.

It is not certain in what form the arsenic is present. Stibnite does not usually contain arsenic, and, on the other hand, no separate arsenical mineral could be recognized.

That stibnite and pyrite could be of clastic origin is entirely out of the question, and I believe it absolutely certain that they have been deposited by the hot waters which permeate the gravel. Considering that the waters have been shown to contain a considerable quantity of antimony, the occurrence seems of great interest.

No metallic sulphides, corresponding in appearance to the normal minerals, were found by Dr. Becker in the sinters, but cinnabar occurs disseminated in the decomposed granite, some distance away from the present springs. The antimonious sulphide, which colors parts of the sinter and always appears red and amorphous, was called metastibnite by Dr. Becker. The absence of ordinary minerals of metallic luster indicated, in a way, a missing link in the chain of evidence to prove the deposition of ores from hot ascending waters; and this link is now supplied by the observations recorded above.

Physical conditions differing very slightly from those at the actual surface will evidently produce crystallized minerals of normal habit and form. Many years ago Senarmont succeeded in forming crystals of stibnite from the amorphous sulphide by heating it to 250° C. in a closed tube with a solution of sodium carbonate.

During the investigation of the quicksilver-deposits of the Pacific slope, Messrs. Becker and Melville found that stibnite is easily crystallized from solutions similar to the waters of Steamboat Springs in sealed tubes heated to about 150° C. This renders it probable that a moderate pressure, such as exists at a small distance below the surface, is sufficient to induce the formation of the crystals described in this paper. Very likely, also, the presence of organic matter in the gravel is one of the conditions favoring such deposition.

Many important deposits of stibnite occur in sedimentary rocks in a manner which renders very probable a genesis somewhat similar to that of the occurrence here described.

Features of the Occurrence of Ore at Red Mountain, Ouray County, Colo.

BY T. E. SCHWARZ, DENVER, COLO.

(Washington Meeting, May, 1905.)

THE publication of the report by Mr. F. L. Ransome[1] was welcomed by many engineers who had mined in the heart of the San Juan country, braved its long and snowy winters, climbed its lofty peaks, run the gauntlet of its snow-slides, and studied its problems of geology, while making dividends for their English or American clients. This report helps one to understand why the bonanzas occurred, and why the inevitable "borrasca" presents itself where least expected.

The Red Mountain district of Ouray county, a very productive section from 1884 to 1893, occupies considerable space in the report mentioned. The character of the ore-occurrence,

[1] A Report on the Economic Geology of the Silverton Triangle, Colorado, by F. L. Ransome, *Bulletin No.* 182, *U. S. Geological Survey.*

being distinctive and presenting many features not existing elsewhere, has been deserving of special study. It is to be regretted that Mr. Ransome was unable to observe the conditions underground, as all the principal properties, many of which I opened and developed, were closed at the time of his investigation. It has been my privilege to have contributed a few brief papers,[2] recording my observations in developing these properties; and it is the object of the present paper to furnish certain sections of the Yankee Girl mine, which throw additional light on the geology of the section and make the available data more complete. The main Yankee Girl chimney or "stock" was the most productive, for the first 500 ft. in depth, of any chimney in the district.

Mr. Ransome describes these ore-bodies as upright stocks, referring to them as follows:[3]

> "It is evident from the descriptions given of the Red Mountain stocks, that the term 'chimney' applied to them is somewhat misleading. They are not simple vertical pipes of ore extending from the surface to indefinite depths, but are separate bodies of irregular, lenticular, or spindle-shaped form, often completely enclosed by country-rock, but linked with neighboring stocks by fissures which are often small and which carry little or no ore"

I cannot agree with Mr. Ransome in the use of the term "stock;" and I regard "chimney" as much more expressive and suggestive of the main features of the occurrence. It seems to me the former term applies no better to the Red Mountain ore-bodies than to those of the Bassick or Bull-Domingo mines of Custer county. One of the features of the ore-bodies of Red Mountain is this very persistence in depth, proven in the Yankee Girl, Congress, Genesee-Vanderbilt, Silver Bell, and Guston mines, to the depths attained. I do not recall a single instance of a chimney on the above-named properties where the terms "lenticular" or "spindle-shaped" would apply as descriptive of the form of the ore-bodies. Their formation by replacement of the breccia is well proved; and the merging of the ore, which occurs massive and quite free from silica or waste, into the country-rock on nearly all sides is characteristic. It is true they were sometimes very erratic and difficult to follow, espe-

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[2] The Ore-Deposits of Red Mountain, Ouray County, Colo., *Trans.*, xviii., 139-145 (1889-90). Also xxvi., 1056-1059 (1896).

[3] *Op. cit.*, p. 107.

cially in the upper levels, owing to the absence of any defined slip or fracture leading to the ore-body, or connecting two or more chimneys.

In opening a new level, the "ore-break," or belt of altered

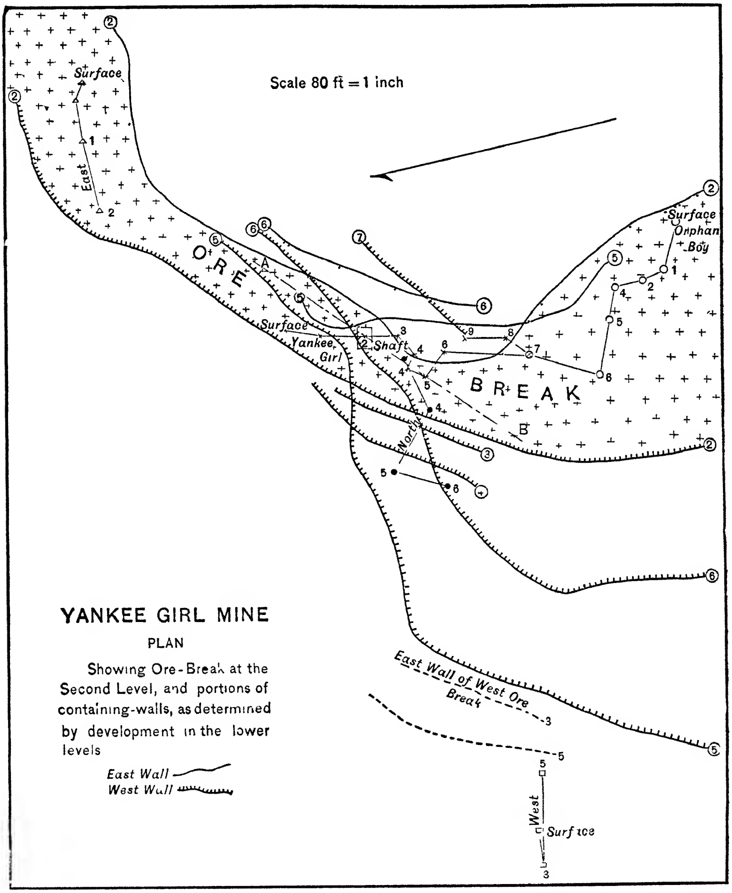

FIG. 1.—PLAN OF YANKEE GIRL MINE, SHOWING ALSO THE POSITION OF CENTERS OF CHIMNEYS.

breccia in which the chimneys occurred,[4] was first located. In this area there might be some one fracture-plane, perhaps very obscure, which if followed would lead to a chimney; but

[4] *Trans.*, xxvi., 1056–1059 (1896).

as such planes rarely had the same course on two successive levels, the finding of the "quartz" or siliceous envelope of the shoot was, in the upper portions of the ore-bodies, the first notice of their proximity. The difficulty of following the "pay" was increased by the utter uncertainty of the position of the areas of massive andesite. (See Fig. 1.) These well-defined masses enclosed no ore-bodies, and were very undulatory, both vertically and horizontally. Whether any of these should be properly described as intrusive dikes, I have never fully satisfied myself, although they possess nearly all the characteristics of a dike. Their course on the surface is more nearly east and west than the course of the general fracturing, which is placed by Mr. Ransome at N. 20° E. This was well illustrated by the Guston chimney, which, in its course in the Guston-Robinson "ore-break," follows a fracture between the third and fourth levels directly through one of these dike-like masses which extends up the mountain from the Guston into the Little Annie claim. Except in the above-mentioned instance, I do not know of any ore-body crossing or entering rock of this character.

While Mr. Ransome refers to the occurrence of these areas of massive andesite and to intrusive dikes in this section, their relation to each other and to the ore-bodies is not mentioned. I presume, however, that these features will be covered by the forthcoming report by Mr. Whitman Cross upon the geology of this district.

One of the distinctive features of these chimneys is the silicified andesite envelope, which, as in the National Belle, Congress, Guston, Robinson, and White Cloud mines, projects in massive knolls of "quartz" above the surrounding surface, and marks their outcrop. This siliceous matrix of the ore-bodies is largest near the surface, decreasing in size and hardness with depth, until it finally ceases to be an envelope of the chimney; and the enclosing rock becomes comparatively soft, altered andesite. Its occurrence seems to be parallel with that of the higher-grade ores, which would indicate that it was a feature of the zone of secondary enrichment.

The accompanying sketch of the Yankee Girl chimneys, given in Fig. 2, shows the position of the center of each ore-chimney on the different levels covered by the notes, and of the bound-

ing-faces of massive andesite, which enclose the ore-break. The development on the successive levels was not sufficient to show the limits of the ore-break at all points; therefore, the position of the andesite faces is outlined only so far as it has been practically disclosed by drifts. It will be observed that the several chimneys gradually approach the largest, or Yankee Girl chimney, in depth. The Orphan Boy and the Yankee Girl chimneys joined between the sixth and seventh levels, as shown in Figs. 2 and 3. On the sixth level, just above the nearly horizontal clay-seam, which is referred to by Mr. Ransome,[5] a distinctly solid body of ore occurred connecting these two chimneys for nearly 6 ft. in height and 60 ft. in length. There was no faulting on this flat seam, as has been stated, but there was a very marked change in the character and grade of the ore. After the Yankee Girl ore-body passed below it, the stromeyerite, which occurs above, ceased entirely, and massive bornite occurs, which is rare above this point.

Referring again to this cross-fracture, I see no reason for assuming that it is identical with the fault-plane which occurs below the seventh level of the Guston mine, as stated by Mr. Ransome.[6] The evidence was that it antedated the ore-deposition, and in fact there are but slight indications anywhere in the mine of displacements or fracturing after the ore was deposited.

It is interesting to note the increasing percentage of bismuth in the ores of the upper levels (from 300 ft. to 500 ft. in depth) of the mines on the line of the main fracturing, from those on the south and highest in elevation to those on the north and on lower ground. In the Congress mine on the extreme south and near the divide, the ores are almost entirely enargite. Proceeding down the valley the Hudson and St. Lawrence ores show appreciable quantities of bismuth, which increase in the Genesee-Vanderbilt, Guston, and Silver Bell mines, in the order named. The latter property produced massive bodies of ore high in bismuth, and carrying from 500 to 1,000 oz. of silver per ton. The ores of the Yankee Girl mine are not included in this comparison, being to the west of the main fracturing mentioned; however, they carried but little of the bismuth minerals.

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[5] *Op. cit.*, p. 218.

[6] *Op. cit*, p. 108.

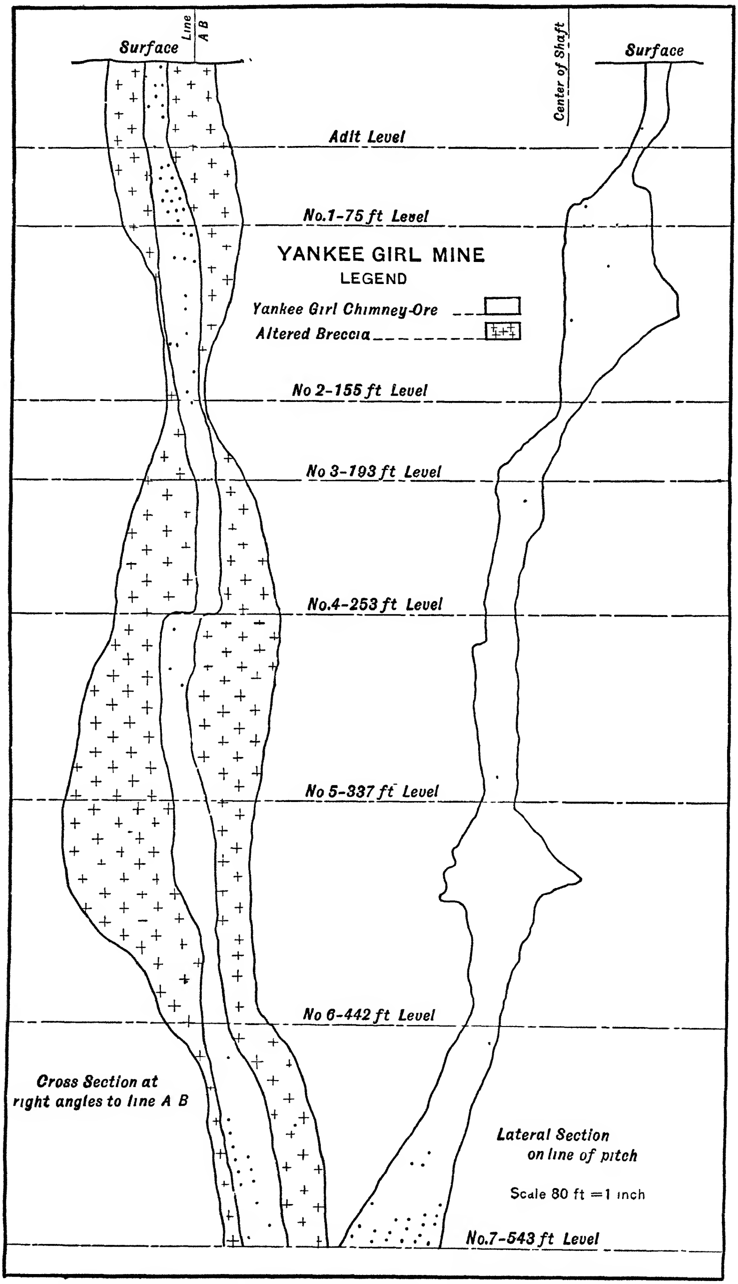

FIG. 2.—SECTION OF MAIN CHIMNEYS IN YANKEE GIRL MINE.

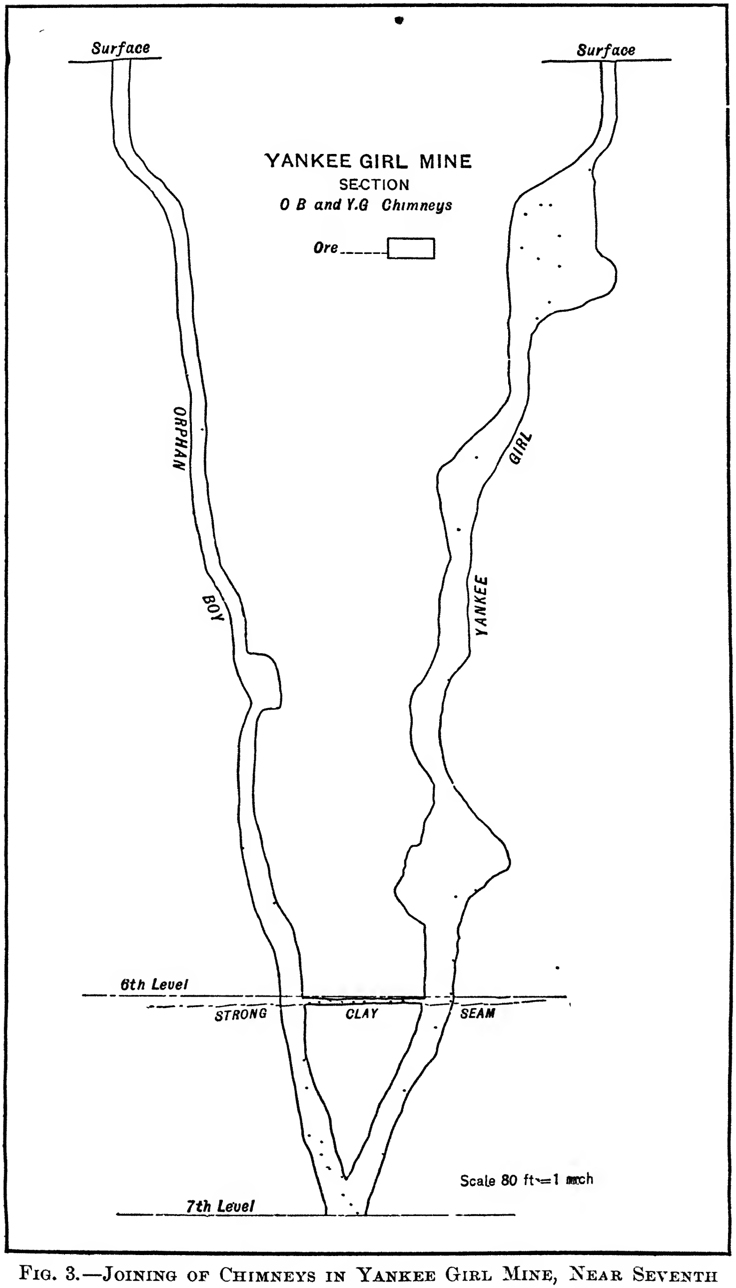

FIG. 3.—JOINING OF CHIMNEYS IN YANKEE GIRL MINE, NEAR SEVENTH LEVEL.

Fig. 2 gives the sections of the main chimney of the Yankee Girl mine from the surface to the seventh level, and shows the ore-body itself, the altered andesite and siliceous envelope filling the ore-break, and the bounding-faces of massive andesite between which the chimneys occur.

There are therefore many features of the ore-occurrence in this section, which should be more fully studied and which might be discussed with profit.

The Yankee Girl chimney is, as Mr. Ransome points out, a notable instance of secondary enrichment. On the theory of descending acid-solutions, the seam referred to as occurring just below the sixth level, evidently induced a concentration of silver-values above that point, at the same time allowing the copper-values to pass through it and enrich the ore-body below, and accounted for an entire change in the mineralogical character of the ore.

What were the ores of the upper portions of the Yankee Girl and Guston chimneys, previous to the scoring-away to the present level? They showed low-grade lead-ores at surface, followed by increasing percentages of copper, the disappearance of lead, and the marked occurrence of the rich silver, copper and bismuth combinations. Is it not probable that enargite existed in higher horizons, as it forms the ore of the chimneys on higher ground to the south? In the National Belle mine, it occurs as a principal mineral in an ore-body 75 by 60 ft. in area, and appears in all the workings as the sulphides occur in depth. In the Congress mine it is the ore to the lowest level (450 ft.), and it occurs also in the upper workings of the Genesee-Vanderbilt mine.

The paper by Mr. Walter Harvey Weed,[7] explaining the occurrence of enargite in the Butte mines, as a secondary product deposited by ascending alkaline-solutions, is very interesting in this connection, and many of the features of the Red Mountain chimneys seem in accordance with this theory.

I desire therefore to call special attention to the following features of the occurrence of ore in the Red Mountain district, viz.:

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[7] Ore-Deposition and Vein-Enrichment by Ascending Hot Waters, *Trans.*, xxxiii., 747–754.

1. That the ores have occurred in persistent chimneys, to which the term "stocks" does not well apply.

2. That in the upper zones—from 300 to 500 ft.—well-defined fracture-planes, bounding an ore-body or connecting two or more of them, were not much in evidence. The wet fissures filled with clay, described by Ransome,[8] became marked features only with depth.

3. That the masses of blue, blocky, unaltered andesite, resembling dikes, outcrop on the surface with approximately east and west courses, and make an angle from 70 to 90° with the course of the general fracturing.

4. That the siliceous envelope of the chimneys is a marked feature on the surface and in the upper levels, gradually disappearing with depth.

5. That enargite occurs but sparingly in the Yankee Girl and Guston chimneys, while it is the ore of the chimneys to the south on higher ground.

Origin of Orbicular and Concretionary Structure.

BY WILLIAM P. BLAKE, DIRECTOR OF THE ARIZONA SCHOOL OF MINES, TUCSON, ARIZONA.

(Washington Meeting, May, 1905)

THE phenomena of concentric arrangement of minerals in rock-masses, generally known as "orbicular structure," have of late received much attention from investigators.

Lawson, of the University of California,[1] has described the orbicular gabbro at Dehesa, San Diego county, Cal. Kessler and Hamilton, of Stanford University, working independently upon the same subject, published their descriptions,[2] giving also a list of many other localities in Europe and America where orbicular rocks are found, adding copious references to the literature of the subject.

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[8] *Op. cit.*, p. 103.

[1] *Bulletin of the Department of Geology, University of California*, vol. iii., No. 17, pp. 383–390 (March, 1904).

[2] The Orbicular Gabbro of Dehesa, California, by H. S. Kessler and W. R. Hamilton. *American Geologist*, vol. xxxiv., No. 3, pp. 133–140, with four plates (September, 1904).

The orbicular diorite of the type-locality in Corsica, familiar to mineralogists and petrologists under the name "Napoleonite," was described by Vogelslang in 1862.[3]

Chrustschoff, of St. Petersburg, has also given much attention to the subject, and is the author of a classification of the various known forms of orbicular structure.[4]

No complete and satisfactory explanation of the origin of orbicular aggregations in rocks has yet been offered. The patent fact is generally recognized that the constituent minerals have crystallized from a more or less molten or plastic magma, but why these minerals should be arranged in concentric spheres or crusts has not been clearly shown. Vogelsang, for example, suggests that this concentric arrangement may be due to irregular areas of cooling and contraction. He wrote:[5]

"When a molten magma consolidates, an irregular cooling may produce greater contraction of the mass at certain points, and this may lead later on to a spheroidal separation. If this condition is arrived at after the point of consolidation of the several minerals has passed, and therefore after their separation is complete, we get, indeed, a concentrically laminated body, but one without definite arrangement of the constituents. This is the well-known spheroidal structure of many eruptive rocks If, on the other hand, the tendency to form spheroids is developed during the period in which a differentiation of the magma into its various minerals can still take place, the latter will undergo a definite arrangement with regard to the central point."

These views are adopted substantially by Kessler and Hamilton. The chemical analyses made by them of the spheroidal masses and of the matrix separately do not show any great difference of chemical composition. This leads them to observe that the similarity seems to denote that the cause, which set about the formation of the spheroids, was not a chemical phenomenon.

Lawson, in discussing the origin of the structure, recognizes magma-differentiation presented in a two-fold aspect, primary in the magma and secondary within the orbule, noting that the structure is rhythmically recurrent. He makes an important suggestion in explanation of the fairly uniform size of the or-

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[3] *Sitzungsber d. neiderrhein Ges.*, vol xix., p 185 (1862)

[4] This classification which appeared originally in the *Memoires de l'Academie Imperiale des Sciences de St Petersbourg*, VII Series, tome xlii., No 3, is quoted by Messrs. Kessler and Hamilton from a paper by F. D. Adams in *Bulletin of the Geological Society of America*, vol. ix, p. 170 (1898).

[5] *Sitzungsber d. neiderrhein Ges.*, vol. xix., p. 185 (1862), cited by Kessler and Hamilton, *American Geologist*, vol. xxxiv., p. 140 (September, 1904).

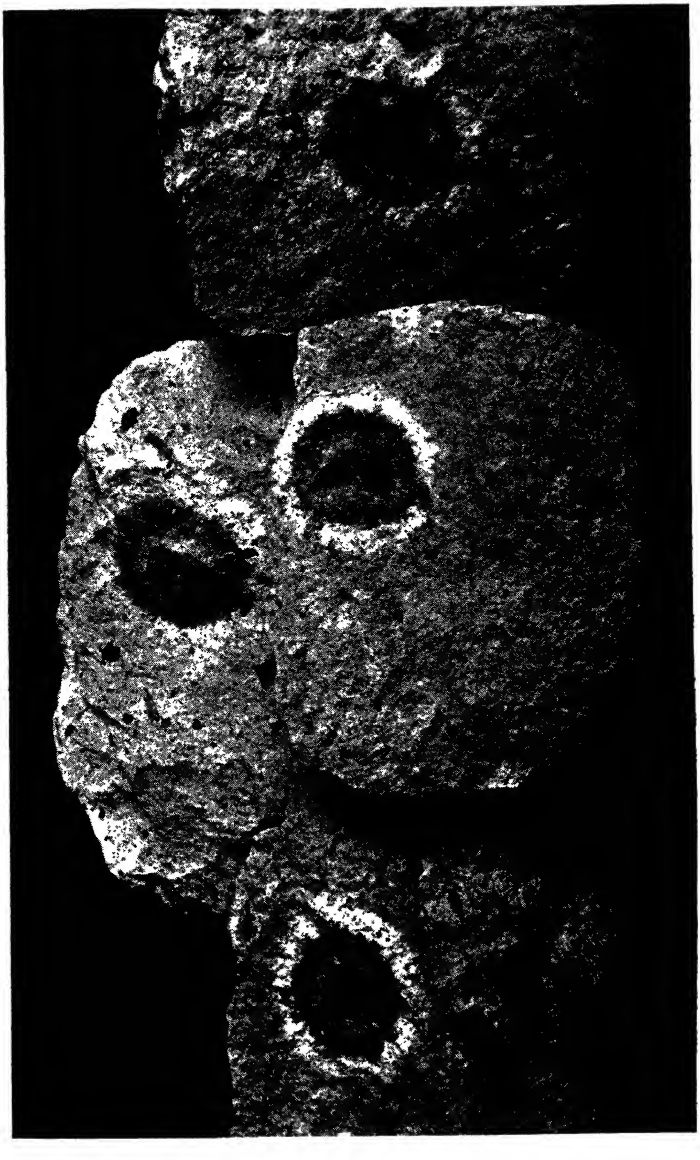

Fig. 1.—Specimens of White Volcanic Tufa from Tucson, Ariz. (One-Third Size), Showing Concentric Nodular Structure.

bules, and the approximately uniform spacing of their centers, stating: "This dimensional factor in the problem seems to indicate the spacial limits of osmotic currents within the time necessary for crystallization."

Dana regarded orbicular diorite as concretionary, remarking that solidification after fusion often produces concretions in the mass. Geikie describes orbicular structure as one in which the component minerals of a rock have crystallized in such a way as to form spheroidal aggregations sometimes with internal radial or concentric grouping.

Similar rocks are known to Germans as *Kugel-granite*, or concretionary granite. Chrustschoff is said to regard them as contact-phenomena and due to the crystallizing of the granite material about pre-existing fragments of other rocks One of the more striking examples is shown by a full-page plate.[6]

The general opinion of these and other writers upon the subject, thus appears to be that the phenomena of orbicular structure are concretionary and due to eutectic magmatic differentiation. While concretionary structure is recognized, there is no good explanation of its origin.

The study of the white volcanic tufa of Tucson, Ariz., especially of that from the San Xavier quarry, appears to give additional light upon the subject, more particularly on the earlier or initial stages of the formation. This rock contains at intervals good examples of concentric nodular structure analogous to the orbiculites of Corsica and Dehesa, but in the tufa they are amorphous and not crystalline. They appear upon fractured surfaces of the rock as colored areolæ formed by a series of concentric rings with an aggregate diameter of from 1 to 2 inches. Their general appearance with the exception of color is fairly well shown by Fig. 1, which illustrates a group of hand-specimens reduced to one-third size..

The tufa is an excellent example of this class of rocks. It tells the story of its origin by its position, internal structure and composition. That it was originally an outflow of thick pasty volcanic mud is shown (1) by its fragmentary composition, (2) by the absence of distinct stratification, (3) by included fragments of other rocks and (4) by its relative position

[6] *Report of the U. S. National Museum, Smithsonian Institution*, p 50, and Plate 6 (1900).

to older and later lava-flows with which the Tucson tufas are generally interbedded. These tufas, being highly siliceous and comparatively uniform in composition, compact and firm in texture, breaking in any direction equally well, easily trimmed into dimension-stone, and porous, afford an excellent building-stone and are extensively so utilized. The specific gravity of the stone of the San Xavier quarry is 2.58 and its absorption capacity 5 per cent.

The rock is apparently the result of an explosive disintegration of a highly-acid crystalline rock producing such a magma as would result from the contact of highly heated quartzose-granite, or possibly a rhyolite, with water. But fragments of feldspar, if any once existed, have mostly disappeared by complete kaolinization. There are traces only of mica, but there is an abundance of free quartz in the form of broken quartz-crystals, some of them retaining the original crystalline faces. The whole mass appears to be cemented by silica The following analysis[7] shows that the rock is essentially siliceous: SiO_2, 78 50; Al_2O_3, 17.50; FeO, 0.90; CaO, 1 35: MgO, trace; Alkalies, not determined; H_2O, 0.23 per cent

The composition is practically that of rhyolite, so-called, but the rock is without any of the physical characters which would indicate flowage as a molten mass or which would justify the appellation of rhyolite It is a mechanical aggregate, but has become firmly cemented apparently by soluble silica There are many inclusions of fragments of other rock, some of them of a dark color, but all with sharp angles and edges, not in the least altered or changed in composition; other fragments show that the permeating ground-water has acted upon them producing chemical changes resulting in concentric deposition and structure.

Usually five distinctly different colored rings can be counted around a partly or wholly decomposed nucleus. The outer ring is the broadest and appears to be a simple discoloration or bleaching of the rock by the removal, probably of ferrous iron; this apparently being the cause of a prevailing lavender or violet tint of the magma whenever the rock is wet. The tufa may be regarded as an absorbent medium—a spongiform frame-

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[7] Made by Mr. Will W. Brostrom, Assayer and Chemist of the Arizona School of Mines.

work within which chemical changes take place between traversing solutions and certain inclusions, the rock itself not being greatly attacked or changed. All the phenomena indicate that the formation of the concentric layers in the substance of the tufa, but without any distinct separation from it or from each other, is essentially chemical. It is evident that the solutions have been formed and have spread outward and around a decomposing or soluble central nucleus by absorption or osmosis, for when the chemical change of the nucleus began there must have been an osmotic flow outwards spreading radially and concentrically with a reciprocal inward flow of other solutions drawn by affinity and producing, by intermingling, precipitates of more or less definite mineral composition in concentric crusts in an amorphous condition, but of such a nature that they would assume definite crystalline form when exposed to favoring conditions.

Such, in general outline, appear to have been the conditions of formation of these amorphous orbiculites of the Tucson tufa, which may be regarded as exhibiting the early or primal stages of orbicular structure and as throwing much light upon its origin and upon the origin of ordinary concretions.

Gas-Producer Power-Plants.*

BY SAMUEL S WYER, COLUMBUS, OHIO

(Washington Meeting, May, 1905)

THE installation of the gas-producer power-plant in America has been so unusual that all engineers have viewed it with interest; a large majority, however, regard it with a lack of confidence and many with positive distrust. Despite the fact that

* By arrangement with the author, the material of this paper, together with that of the two papers, Bibliography of Gas-Producers, and the Testing of Gas-Producers, have been taken for publication from his complete monograph entitled *Gas-Producers*, which is to be published by the Engineering and Mining Journal Co., New York. In this monograph the following subjects are treated :—1. Status of producer-gas. 2. Classification of producer-gas. 3. Manufacture of producer-gas. 4. Efficiency of gas-producers. 5. Use of steam in gas-producers 6. Effects of CO_2. 7. Thermal calculations. 8. Combustion of producer-gas. 9. Heat-balance of the producer. 10. Fuel for gas-producers. 11. History of gas-pro-

European engineers have usually been less inclined to take the initiative along experimental lines than are Americans, they have, nevertheless, developed the gas-producer plant to a very high state of efficiency to which they were forced by the necessity of economy in fuel-consumption.

The gas-producer power-plant is so common in Europe that engineers, as well as the general public, regard it with the same degree of confidence that is now universally placed in steam-plants. Gas-engines, both small and large, are in general use there, and central stations, aggregating several thousand horse-power, are quite numerous.

The fact that gas-producer power-plants have received so little attention in America may be attributed to five conditions:—1, ignorance and prejudice; 2, newness of work; 3, inadaptability of gas-engines; 4, fuel-economy not imperative; 5, smoke nuisance not given attention.

1. *Ignorance and Prejudice.*—The only literature pertaining to gas-producer power-plants is that found in the various technical journals and in the *Transactions* of engineering and other technical societies. In many cases the papers are of a fragmentary character, and seldom are they complete or comprehensive. It may be that the lack of reliable data available to engineers is the cause of the ignorance and prejudice that exists concerning this important branch of engineering.

2. *Newness of Work.*—The manufacture of producer-gas is an old process, and gas-engines have been developed to a very high stage of mechanical efficiency, hence there is no valid reason why such installations should be regarded as experimental.

The Winchester Repeating Arms Co., at its plant in New Haven, Conn., has a Loomis-Pettibone gas-producer plant, built primarily to furnish gas for fuel-purposes (such as for annealing-ovens, furnaces, etc.); a 100-h.p. Westinghouse gas-engine, which was installed some time ago, and later three direct-connected units, each of 175 h.p., were ordered. At the present

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ducers. 12. American pressure-producers. 13. American suction-producers. 14 English types of gas-producers. 15. French types of gas-producers 16. German types of gas-producers 17. Scandinavian types of gas-producers. 18. Gas-washers and purifyers. 19. By-product gas-producers 20. Gas-producer power-plants. 21. Hints on operation of producers. 22. Testing gas-producers. 23 Future of the gas-producer. 24 Reference tables. 25. Chronological record of early experiments 26. Bibliography.

time this example is one of the best instances in America of an industrial producer-gas plant where gas is furnished, both for fuel and for power.

The following list comprises some of the larger gas-producer power-plants now in operation in America:

Moctezuma Copper Co., Nacozari, Sonora, Mexico.[1]

The Guggenheim Exploration Co., 700 h.p., Santa Barbara, Chihuahua, Mexico.

Detroit Copper Mining Co., 1,000 h.p , Morenci, Ariz.

Rockland Electric Co., 1,000 h.p., Hillburn, N. Y.

Potosina Electric Co., 600 h.p., San Luis Potosi, Mexico.

Velardeña, Mining and Smelting Co., 2,000 h.p., Velardeña, Durango, Mexico.

The Sayles Bleacheries, 250 h.p., Saylesville, R. I.

It is obvious that much has already been accomplished in this important field of power-generation.

3. *Inadaptability of Gas-Engines.*—No gas-producer power-plant can be successful unless the gas-engine is adapted to suit the particular gas available for its use. On the authority of Westinghouse, Church, Kerr & Co. an engine, which will develop 100 h.p. with natural gas, will give only about 80 h.p. with producer-gas,—a loss of 20 per cent. With a 200-h.p. engine, this loss would be about 15 per cent. and with sizes above 300 h.p. it would be about 10 per cent. Hence, the obvious necessity of designing the engine to suit the particular fuel it is to use. Several failures have been made by neglecting this important point.

4. *Fuel-Economy not Imperative.*—In the list of plants given above, it will be noticed that most of them are in remote regions where the cost of fuel is high, hence the high economy of the gas-producer plant was a feature that commended itself.

5. *Smoke-Nuisance not given Attention.*—The laxity of the laws regarding the smoke-nuisance has not made it imperative for manufacturers to give attention to the prevention of smoke. As soon as regulations concerning the smoke-nuisance are enforced, the gas-producer industry will receive a new impetus on account of the easy solution that the gas-producer plant offers for this trouble.

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[1] *Trans.*, xxxiv., 748–776.

GENERAL DATA.

The following data relative to the design, operation and maintenance of gas-producer plants are given to show their advantages.

1. *Solution of Smoke-Problem.*—A good gas-producer, from the very nature of its construction and operation, does not allow the smoke to escape into the atmosphere; hence the gas-producer itself presents a practical solution for the elimination of the smoke-nuisance. The non-requirement of a chimney means a large saving in the first cost and in the maintenance of a power-plant, and is an additional advantage in plants where the æsthetic features of the design are of importance, for instance, in the case of a municipal power-plant.

2. *Labor.*—The cost of labor required to operate a gas-producer plant is about the same as that required in a steam-plant of similar size. However, during the time that a gas-producer plant is idle, it requires less attention than does a steam-boiler.

In the case of a municipal pumping-station, the labor required to operate the producer-gas plant would be one-half that of a similar steam-plant, the gas-plant being operated as follows:— The gas-producers are to use coal to supply the gas to operate a three-cylinder vertical gas-engine direct-connected to a triplex double-acting power-pump. In this case the usual fire-engine will be dispensed with; and, should a fire occur, the requisite pressure will be obtained by pumping directly into the system. For ordinary domestic supply, the pump will deliver the water into a water-tower, from which the mains receive the supply as needed. In every case the maximum quantity of water required during a fire is much larger than the average domestic consumption; hence the pump must be designed for this maximum quantity. As a result, the working of the pump at its full capacity for 6 out of 24 hr. would furnish enough water for the daily domestic consumption; the pump would usually be operated from 7 to 10 a.m. and from 3 to 6 p.m.

A gas-holder of sufficient capacity to run the pump for 30 min. is to be filled before the producers are closed down.

Compressed air is to be used to start the engine, which may be put into motion simply by moving a lever.

The engineer is to live adjacent to the plant, so that, when an alarm is sent in to the hose-company, and simultaneously to the

engineer's home and to the plant, it would be possible for the engineer to have the pump at work direct into the system, by the time the fire-company could reach the fire and make hose-connections.

Since the gas-holder would supply the engine until the producers could be started, the above scheme of operation eliminates the necessity of a night-fireman and the keeping up of at least 70 lb. of steam-pressure in a steam-plant. A similar arrangement could be equally well adapted for fire-purposes in connection with large industrial plants.

With regard to the skill required, a producer-gas power-plant does not require any greater skilled labor than does a steam-plant of similar size; however, in some cases, it may require time for men, trained to handle steam-apparatus, to become accustomed to gas-engines and gas-producers.

3. *Cost of Installation.*—Two well-known engineering concerns give the following data:

"The cost of gas-power plants, including gas generating plant and gas-engines, up to 500 h.p., is about 25 per cent. higher than the cost of a steam-plant of similar size. Large plants, from 1,000 h.p upwards, cost about the same as a first-class steam-plant of similar size."

4. *Cost of Repairs.*—The cost of repairs on a gas-producer plant will not exceed that of a boiler-plant.

5. *Use of Cheap Fuels*—In order that a gas-producer plant shall be commercially successful, it must be able to make, from a low-priced fuel, gas that is sufficiently clean for use in an engine. Bituminous slack is usually the lowest-priced fuel to be had; however, anthracite-culm, or even wood, may be cheaper in some localities. In all cases the percentage of sulphur must be low if the gas is to be used in a gas-engine.

Frequently, the use of a mechanically-washed coal will be economical.

6. *Scrubbing the Gas.*—The only reliable way to remove tar and other hydrocarbons from gas made from soft coal is to have the producer so arranged that the gas comes in close contact with an incandescent mass of carbon. No mechanical means of removal has yet been found to be successful, although several forms of centrifugal apparatus have been tried. For the removal of fine dust-particles, however, centrifugal fans have proved very satisfactory.

7. *Fuel-Economy During Hours of Idleness.*—The "stand-by" loss of heat is very small, being limited to radiation only; a gas-producer is tightly closed during the time it is not making gas and the entrance of air is thereby prevented. This feature is a marked advantage over a steam-boiler under similar conditions.

8. *Time Required to Start Producers.*—Even after a producer has been idle for several hours, it may be started and can be working at its full capacity within 15 minutes. A gas-holder is generally used in connection with the producer, from which a supply of gas can be taken to start the gas-engine instantly and keep it in operation until the gas-producers are making gas.

9. *Time Required to Stop a Gas-Producer.*—A gas-producer may be stopped instantly by simply shutting off the supply of air and steam.

10. *Composition of the Gas.*—The gas from the gas-producer is quite uniform in composition, and as it usually passes first to a holder before reaching the gas-engine, it becomes thoroughly diffused, thus insuring a still greater uniformity.

11. *Thermal Efficiency.*—The thermal efficiency of gas-producers is generally about 80 per cent. and in some cases it is even higher than this value.

12. *Automatic Feeding.*—It is much easier to use an automatic feeding-device on a gas-producer than on a steam-boiler, because all producers are placed vertically and the fuel can be dropped into position by gravity. The use of an automatic feed always decreases labor and insures more uniformity in the composition of the gas produced.

13. *Rate of Gasification*—The rate of gasification in a gas-producer is relative to the character of the coal used. The best rate determined by experience is 12 lb. of coal per sq. ft. of grate-area per hour, although some makers have advised as high as 20 lb. of coal. Experience has also demonstrated that too-rapid driving opens a wide door for the admission of adverse gasifying conditions.

14. *Poking the Gas-Producer.*—The amount and frequency of poking a gas-producer will depend on the nature of the fuel and the design of the producer The mechanical agitation of the fuel-bed (as in the Kitson and Fraser and Talbot producers) eliminates poking entirely. In using bituminous coals, the

difficulties of clinker-formations is augmented by the production of coke. The judicious use of a steam-blast and automatic feeding will generally reduce poking to a minimum and, in some cases, will eliminate it entirely Hand-poking is very laborious for the attendant and usually it will be shirked whenever possible. Gas will usually escape around the poke-holes while the producer is being poked, which will vitiate the air in the producer-room and also effects the regularity of the composition of the gas.

15. *Calorific Value of Producer-Gas.*—The calorific value of producer-gas varies from 125 to 150 B.t.u. per cubic foot.

16. *Economy.*—The generation of one brake horse-power per hour with from 1 to 1.25 lb. of coal or 3 lb. of wood, is very common producer-gas power-plant practice at the present time, and the gas contains at least 80 per cent. of the heat-energy resident in the fuel.

17. *No Loss from Condensation.*—A very important advantage of the producer-gas installation is that the gas does not condense or lose power on its way to the gas-engine. On the contrary, the cooler the gas the better it is for the engine. With steam, the condensation is considerable.

18 *Leakage of Gas*—It is easy to prevent leakage of gas from the piping, owing to the low pressure of the gas (about 2 in. of water); whereas, with steam, there is often much loss and inconvenience on this account.

19. *Saving in Shafting.*—By using isolated engines, a large saving in shafting may be made in many cases. It is not possible to do this in steam-plants and still maintain a good economy.

20. *Floor-Space.*—The floor-space required for gas-holders, gas-producers and auxiliary apparatus is about the same as that required in a steam-plant; the holder, however, need not be placed adjacent to the producers, but at any other convenient place.

21. *Control of Operation.*—A gas-producer plant is under much better control than the average steam-plant, because in the gas-producers the air-supply rate of gasification, as well as the fuel-supply, can be regulated more easily.

22. *Storing of Heat-Energy.*—One of the most potent advantages of the gas-producer plant compared with the steam-plant is the ability of the former to store the heat-energy in a holder

where it may be drawn upon for immediate use. In this way irregularities and fluctuations of load need not effect the regularity of the action of the gas-producer. This condition means an economy of operation and a convenience of use that are impossible with any steam-plant.

23. *Dual Use of Gas.*—Another important advantage of the gas-producer power-plant is that, in many cases, the gas may be used both for power and for metallurgical purposes, the same pipes being used to supply engines and furnaces. The plant of the Winchester Repeating Arms Co., at New Haven, Conn., illustrates an installation of this character.

24. *Economy of Water.*—In many cases it is a serious matter to secure a sufficient supply of water for a steam-plant and sometimes, even with an adequate supply, the quality of the water is such that it is entirely unfit for use in a steam-boiler. One of the most annoying difficulties of many steam-plants is the trouble caused by the corrosion and subsequent cleansing of the boilers, together with the maintenance of feed-water purifiers.

The gas-producer power-plant forms an almost ideal solution of the problem of water-supply. With a producer in normal condition, the consumption of water will not exceed 2 lb. per brake horse-power hour. The water used in cooling the gases in the scrubber may be cooled in a simple tower and used repeatedly.

25. *Operating Isolated Machines.*—There is no difficulty in piping the gas for several thousand feet in order to reach an engine that drives an isolated machine; this often makes it possible to dispense with abnormal lengths of line-shafting and the consequent friction-loss, or other unsatisfactory methods of power-transmission. This condition is especially valuable in places where electrical power is not used.

26. *Range of Sizes.*—Standard gas-producers now range from a few horse power to more than 500 h.p. in size.

27. *Danger from Explosion.*—There is less danger of explosion in a gas-producer plant than there is in connection with a steam-plant; moreover, should an explosion occur, it would be much less violent and destructive than that of a steam-boiler.

28. *Location of Producer-Plant.*—If desired, the gas-producer plant may be placed near the fuel-supply, which, in many cases,

would reduce the expense of transportation, the gas being piped to the gas-engines or furnaces where it is to be used. This arrangement, which is impossible with a steam-plant, means a decided saving in favor of the gas-producer installation.

29. *Future Field for Gas-Producers.*—The preceding paragraphs show the many strong advantages of the gas-producer as a power-generator; the large number now in successful operation shows that the experimental stage has been passed and that they have become a formidable competitor of the steam-boiler. The time is not far distant when three classes of gas-producers will be in common use: I. locomotives for railroad service; II. portable engines; and III. power-plants for marine service.

The advantages of the gas-producer for each of the above three classes are briefly summarized as follows :—

I. Gas-Producer Locomotives are,—

1. *Smokeless*: (*a*) trains and stations may be kept cleaner; (*b*) tunnels may be passed through with greater safety; (*c*) comfort of passengers will be increased.

2. *Cinderless*: (*a*) fuel-loss will be decreased; (*b*) comfort of passengers will be increased; (*c*) large fire-losses due to sparks will be eliminated entirely; (*d*) insurance-rates on property adjacent to railroads will be less.

3. *More Economical*: (*a*) in fuel, since the amount used would be less than one-half that used on steam-locomotives; (*b*) in water, since the amount used would be less than one-eighth that used on steam-locomotives; (*c*) in time, since the time required to take fuel and water will be less; (*d*) in labor in firing, on account of automatic feed and decreased amount of fuel used; (*e*) in idleness, since stand-by losses are very low; (*f*) in the number of fuel- and water-stations required.

4. *Safer*, since the danger of boiler explosions is eliminated

II. Gas-Producer Portable Engines are,—

1. *Smokeless:* (*a*) large fire-losses due to sparks will be eliminated entirely; (*b*) insurance-rates on property adjacent to where an engine is used will be less.

2. *More Economical;* (*a*) in water; (*b*) in fuel; (*c*) in labor; (*d*) in time required to secure fuel and water.

3. *Safer*, the danger of explosion being eliminated.

III. Gas-Producer Power-Plants for Marine Service are,—

1. *Smokeless*: (*a*) ships may be kept cleaner; (*b*) passengers will have more comfort; (*c*) a battleship could conceal its position more easily.

2. *More Economical;* (*a*) in fuel; (*b*) in water; (*c*) in time required to secure fuel; (*d*) in bunker capacity; (*e*) in floor-space; (*f*) in apparatus required, since all of the condensing machinery would be dispensed with.

The Testing of Gas-Producers.*

BY SAMUEL S. WYER, COLUMBUS, OHIO

(Washington Meeting, May, 1905.)

The following description of methods for conducting gas-producer tests is probably the first attempt to give the subject an analytical, thorough and comprehensive treatment.

In some cases where tests have been made, the methods have been so unsystematic and ambiguous that it has been impossible to secure comparable results. To eliminate this difficulty, the following provisional code of gas-producer tests—which has some resemblance to the code of boiler-trials of the American Society of Mechanical Engineers—has been developed.

The primary object in testing a gas-producer is to determine whether the producer is working satisfactorily or, what is the same thing, to see if the efficiency is as high as it should be with the type of producer in question; and also to find out if the composition of the resulting gas is adapted to the work it has to do.

In order that the test shall be of any value, it must be thorough and comprehensive, and must be conducted with skill and care. When so conducted, the test will reveal the economy of the producer; and, by making suitable changes, the efficiency will often be increased very much. As a result of the tests made by Jenkins,[1] the efficiency was raised from 56.2

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* Taken for publication from Mr. Wyer's monograph, *Gas-Producers* (see p. 44 of this volume of the *Transactions*).

[1] *Proceedings of the Institution of Civil Engineers*, vol. cxxiii., p. 328 (1895–96).

to 71.2 per cent. This shows the large saving that may frequently be made in the fuel-consumption by studying the results of a careful test. The log of the test, given in Fig. 1, shows that, just as soon as the temperature became regular, the percentage of CO_2 decreased and that of CO increased.

Rules for Conducting Gas-Producer Tests.

1. *Determination of Object.*—Determine at the outset the specific object of making the test,—whether it is to ascertain the capacity of the producer, its efficiency and defects, or the effect of changes of design, proportion or operation,—and prepare for the trial accordingly.

2. *Examination of the Producer.*—Examine the producer in detail, ascertain the dimensions of grates, contour of inner walls, determine the angle of the bosh-wall with the vertical, make a full record describing the same and illustrate special features by sketches. If possible, secure a drawing or make one giving all the general dimensions of the producer.

3. *General Condition of Producer.*—Notice the general condition of the producer and its equipment, and record such facts in relation thereto as bear upon the objects in view.

If the object of the trial is to ascertain the maximum economy of the gas-producer, the producer and all of its appurtenances should be put in first-class condition. Remove clinkers from grates and from the sides of the walls. Remove all dust, soot and ashes from the chambers, gas-connections and flues. Close air-leaks in the masonry and poorly-fitted cleaning-doors. See that all dampers will open wide and also close tight. Test for air-leaks by passing the flame of a candle over cracks in the brick-work.

4. *Character of Fuel.*—Determine the character of the fuel to be used. For tests of the efficiency or capacity of the producer for comparison with other producers, the fuel should, if possible, be of some kind which is commercially regarded as a standard.

5. *Calibration of Apparatus.*—Establish the corrections of all apparatus used in the test for weighing and measuring.

These are:—

(*a*) Scales for weighing coal and ashes (and water if an auxiliary boiler is used).

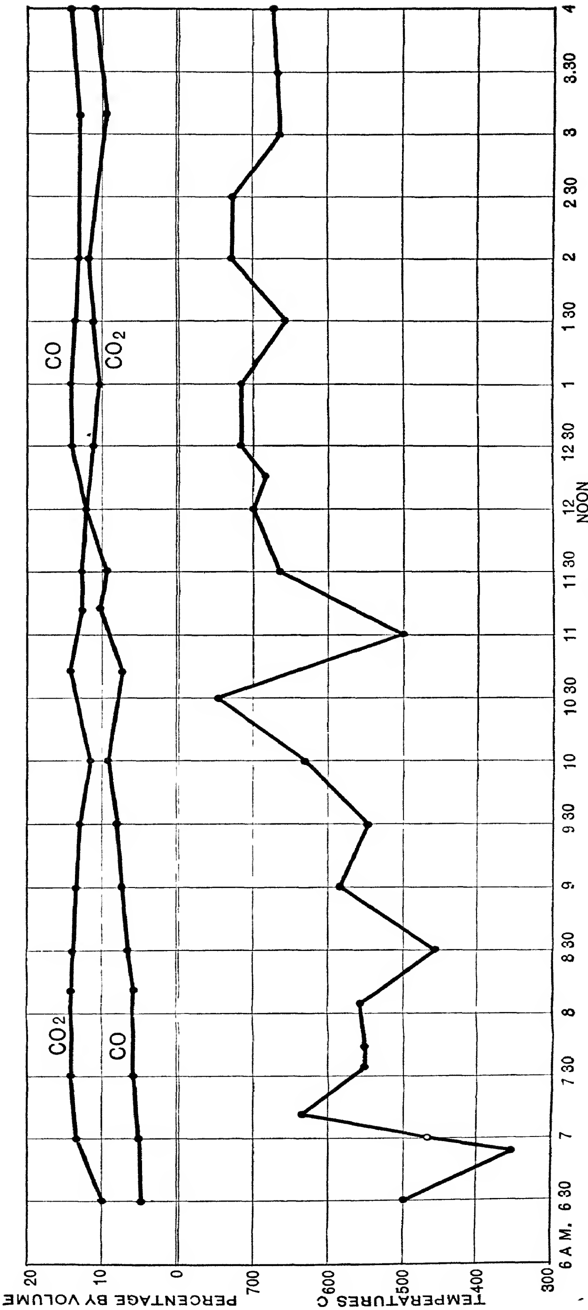

FIG. 1.—CHART SHOWING THE RESULTS OF A GAS-PRODUCER TEST.

(*b*) Thermometers and pyrometers for taking temperatures; if a thermo-electric pyrometer is used, it must be calibrated with the same lengths of wire and same resistance used in taking the readings.

(*c*) Pressure-gauges, draft-gauges, etc.

(*d*) Apparatus used in making gas-analysis.

(*e*) Anemometers used in measuring air.

The kind and location of the various pieces of testing-apparatus must be left to the judgment of the person conducting the test; always keep in mind the main object, i.e., to obtain authentic data.

6. *Auxiliary Boiler.*—When an auxiliary boiler is used to furnish the steam for the producer, the amount of fuel it consumes must be charged against the producer. The amount of water that the boiler evaporates must also be measured.

7. *Heating of Producer.*—See that the producer is thoroughly heated to its usual working-temperature before the trial.

8. *Duration of Test.*—Of tests made to ascertain either the maximum economy or the minimum capacity of the producer, the duration should be at least 12 hr. of continuous running, after the producer has been brought up to its normal working-condition.

9. *Starting and Stopping a Test.*—The conditions of the producer in all respects should be as nearly as possible the same at the end of the test as at the beginning. The fire should be the same in quantity and condition, and the walls, flues, etc., should be of the same temperature. In no case should the fires be drawn out, as is often done in boiler-tests. In producers that must be shut down for cleaning, it is advisable that the test should cover one continuous phase only.

10. *Uniformity of Conditions.*—Arrangements should be made to utilize the gas so that the rate of gasification may be constant during the test. Uniformity of conditions should prevail as to the pressure of steam and air-blast, the thickness of fire and bed of ashes, the times of firing and quantity of coal fired at one time, the frequency of poking, and the intervals between the times of cleaning the fires.

11. *Keeping the Records.*—Take note of every event connected with the progress of the trial, however unimportant it may appear. Record the time of every occurrence and the time of taking every weight and every observation.

12. *Quantity of Steam.*—When an auxiliary boiler is used for each producer, the amount of steam consumed can easily be determined from the amount of water evaporated in the boiler.

In the absence of an auxiliary boiler, proceed as follows:—after the test has been made, remove the steam-nozzle and calibrate it by determining the amount of steam that will pass through in a unit of time with the same pressure and same percentage of moisture present during the test. Then examine the boiler that is furnishing the supply of steam and determine, as accurately as possible, the quantity of coal used per hour in making the quantity and quality of steam used per hour, and charge this amount of coal to the producer.

The amount of steam may also be determined as follows:—the hydrogen in the gas and water-vapor must come from three sources, namely, coal, moisture in coal, and steam. Since all these quantities are known except the latter, this can easily be calculated.

13. *Quality of Steam.*—The percentage of moisture in the steam should be determined near the nozzle where the steam enters the producer, by means of a throttling- or separating-calorimeter. The sampling nozzle should be placed in a vertical steam-pipe.

14. *Measurement of Ashes and Refuse.*—The ashes and refuse will generally be wet before they are drawn from the producer, especially if a producer of the water-seal type is used. After the test, rake out all the ashes and weigh them immediately; in the meantime set aside a sufficient sample for chemical analysis and weigh it; let this large sample dry in the air until it reaches a constant weight, then reduce it to a laboratory sample and determine the residual moisture. The amount of incombustible material should be accurately determined, and, in this way, the grate-efficiency of the producer should be found.

15. *Sampling the Coal and Determining Its Moisture.*—The same method that is given in the American Society of Mechanical Engineers' code for boiler-trials should be used, with the following exception:—in sizing the sample, crush it to 0.5-in. mesh and air-dry it for 24 hours or more, which is long enough to insure that the quantity of moisture remaining will vary less than 1 per cent.

16. *Calorific Tests and Analysis of Coal.*—The method adopted by the American Chemical Society should be used.[2]

17. *Gas Analysis.*—The gas should be analyzed according to standard chemical methods.

18. *Calorific Value of Gas.*—The calorific value per cubic foot should be calculated from its chemical composition and also determined directly by the Junker calorimeter. The two values thus obtained should correspond closely.

19. *Determination of Water-Vapor, Tar and Soot in the Gas.*—The use of the following apparatus, designed by Prof. N. W. Lord and shown on Fig. 2, is advised.

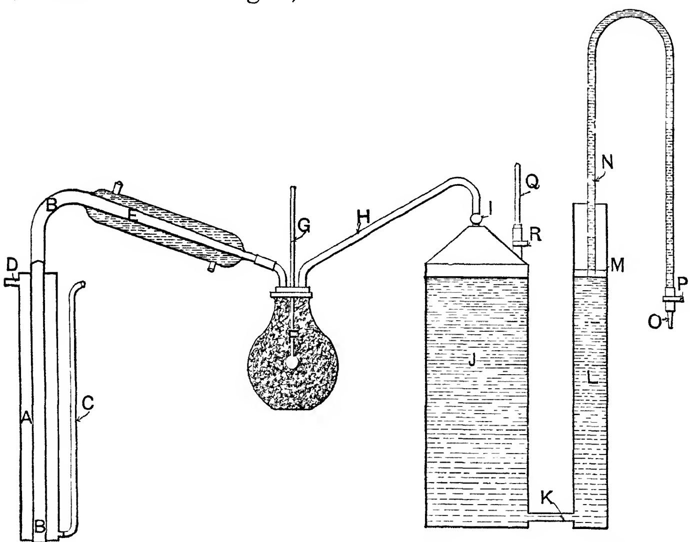

FIG. 2.—APPARATUS FOR SAMPLING GAS, DESIGNED BY PROF. N. W. LORD.

B is the sampling tube, made of 0.5-in. pipe, which is placed in the gas-flue; *A* is an annular jacket surrounding *B*, and has pipe-connections at *D* and *C*.

Live steam is blown in at *D*, and out at *C*, in order that the temperature of the iron pipe, *B*, will be kept below the point at which the iron would act on the CO_2. This procedure will secure a sufficient cooling and yet will leave the temperature high enough to prevent the condensation of moisture.

E is an ordinary condenser through which cold water is circulated.

[2] *Journal of the American Chemical Society*, vol. xxi. (1899), pp. 1116 to 1132.

F is a small flask filled with ignited asbestos-fiber and containing a thermometer, *G*.

J and *L* are tanks filled with water and connected at *K*. *I* is a valve. *H* is a rubber tube connecting *J* and *F*. *Q* is a thermometer placed in a stopper in a pipe with valve, *R*, the object of this valve being to make it possible to remove the thermometer, when gas is in the tank, *J*. *M* is a float to which is fastened the curved glass tube, *N*, which acts as a siphon and which has a small nozzle, *O*, with a pinch-cock, *P*, on the rubber connection. The object of the float and glass tube is to keep a constant head above the nozzle, and thus insure a uniform flow through it. The operation of the apparatus is as follows:—Disconnect the rubber tube, *H*, and fill the tanks, *J* and *L*, with water until it overflows at the valve, *I*; fill the siphon, *N*, with water and close the stop-cock, *P*; attach the rubber tube, *H*, with stop-cock, *I*, and circulate water through the condenser, *E*, and steam through the water-jacket, *A*. Then open valve, *P*; the water will be drawn out of tanks, *L* and *J*, and the gas will be drawn through condenser, *E*, flask, *F*, and tube, *H*, into the top of the tank, *J*. The water in excess of the saturation of the gas at the temperature of the small flask, is condensed, any tar and soot in the gas being retained in the ignited asbestos in the flask. After the test, the flask and its contents are weighed, and the increase over the weight taken before the test, gives the quantity of the tar and water condensed from the volume of the gas which has passed through the flask. This volume is determined by measuring the quantity of water which has run out of the aspirating-tank, *J*, during the drawing of the sample.

The quantity of water remaining in the gas, after passing out of the little flask used as a receiver, is then calculated from the temperature of the issuing gas (which was saturated with water-vapor) by the ordinary saturation-tables. The water in the gas is then the sum of the permanent vapor and that condensed. The water in the flask is determined by drying the contents over sulphuric acid to constant weight and determining the loss. The dry contents are then ignited, and the additional loss of weight is estimated as soot and tar, as follows:

B = barometric pressure.

Tt = temperature of gas in tank.

Tb = temperature of gas-flask.

Vt = volume of wet gas in tank at temperature Tt.

Vs = Vt reduced to 0° C. and 760 mm.

Vd = volume of dry gas at 0° C. and 760 mm.

Bt = aqueous tension of water-vapor corresponding to Tt.

Bb = aqueous tension of water-vapor corresponding to Tb.

W = weight of 1 cubic unit of water-vapor corresponding to Tb.

Wb = weight of water-vapor condensed in flask.

Wt = weight of permanent water-vapor in volume Vs.

$$Vs = \frac{Vt\,(B - Bt)}{760\,(1+0.00366\,Tt)}.$$

$\frac{Bb}{B}$ = percentage by volume of water-vapor in flask.

$\frac{Bt}{B}$ = percentage by volume of water-vapor in Vs.

$$Vd = Vs\left(1 - \frac{Bt}{B}\right).$$

$Vs\,\frac{Bb}{B}$ = total volume of permanent water-vapor in Vs.

$$Vs\,\frac{Bb}{B}\,W = Wt.$$

Wt + Wb = total weight of water carried in volume, Vd, of gas.

From this, the amount of H_2O, tar and soot per pound of coal can be calculated directly.

20. *Report of Test.*—The data and results should be reported in the manner given in Table I. It is also recommended that the full log of the test be shown graphically by means of a chart, represented by Fig. 1.

TABLE I.—*Data and Results of Gas-Producer Test.*

General Data.

1. Test made by. . ...
2. Test made to determine... . . ..

. . ..

3. Chemical analysis made by ... .
4. Type of producer. . . . .
5. Producer built by. ....
6. Date of installation.. . ...
7. Kind of fuel .. ..
8. Form of grate........... ....

9. Form of ash-pit........................ ....
10. Form of blower....... ....
11. State of weather. .. ..
12. Barometer in producer-room...... .. ..
13. Date of test.. . . ..
14. Duration of test. . .. .

Dimensions of Producer

A complete description and drawings of producer should be given on an annexed sheet.

15 Grate-surface ... Width . . Length ... .
Diameter . . .. . Area . . .
16. Height of bed of ashes ....
17. Height of top of fire above grate ....
18. Thickness of ash-zone ... .
19 Position of air-pipes ....
20. Position of steam-inlets. . . . .
21. Diameter of producer. .. . .
22. Inclination of bosh-wall .. . .

Average Pressures

23 Steam-pressure near nozzle (lb per sq in.) . . . .
24. Force of draft in ash-pit (in. of water). . ...
25 Force of draft in gas-flue (in. of water).. ....
26 Steam-pressure in auxiliary boiler (lb per sq in.) . .. .

Average Temperatures.

27. Of external air. . ...
28. Of producer-room ....
29 Of steam near nozzle ....
30 Of air entering pre-heater . . . .
31. Of air entering producer . . ..
32. (Number of degrees of pre-heating) . .. .
33 Of escaping gases from producer . ...
34. Of escaping gases from economizer.. . .. .
35. Of ash-pit . . . .
36. Of ash-zone . .. .
37 Of combustion-zone. ....
38. Of decomposition-zone . . . .
39. Of distillation-zone .. ..
40. Of feed-water entering auxiliary boiler . ...
41. Of water entering jacket . . ..
42. Of water leaving jacket .. ..
43. Of water entering spray... ....
44. Of water leaving spray....... ....

Fuel

45. Size and condition . ...
46. Total weight of fuel fired. ....
47. Percentage of moisture in fuel .. ..
48. Total weight of dry coal consumed . . ..
49. Total weight of ashes as drawn out.. . ...
50. Percentage of moisture in ashes.. . ...
51. Total weight of dry ashes.... . ...

52. Percentage of carbon in dry ashes.. . . . .
53. Total combustible consumed ... .
54 Percentage of incombustible in dry coal . . ..
55. Total combustible consumed in auxiliary boiler. ....
56. Total combustible required to generate the steam used in producer when the producer was used without its own auxiliary boiler . . . .
57. Total amount of combustible used in the production of the gas. .. . .

Proximate Analysis of Coal.

	Of Coal Per Cent	Of Combustible Per Cent
58 Fixed carbon	.. .. . .	. . . . . .
59 Volatile matter. .	. . . . ..	.. ..
60. Moisture	. . .	. . .. .
61. Ash . ..	..	. . . . .
	100 per cent.	100 per cent.

		Per Cent
62 Sulphur, separately determined	... .	.

Ultimate Analysis of Coal

	Of Coal Per Cent	Of Combustible Per Cent
63. Carbon (C).	. . ..	. . . .
64 Hydrogen (H) . .	.	.. . .
65 Oxygen (O) . ..	..... .	. .. . .
66 Nitrogen (N)	..	. . . .
67. Sulphur (S) . .	...	. . . .
68. Ash.	..	
	100 per cent	100 per cent

Moisture in sample of coal as received . .

Analysis of Ash and Refuse

69. Carbon . .
70. Earthy matter .. ..

Consumption of Fuel

71. Total fuel consumed per hour in running producer . .
72 Total combustible consumed per hour in running producer . . .
73. Dry fuel per sq. ft of grate-surface per hour consumed in producer itself . .. .

Calorific Value of Fuel.

74. Calorific value by oxygen-calorimeter per pound of dry fuel. . .. . B T U
75 Calorific value by oxygen-calorimeter per pound of combustible .... B. T U
76. Calorific value by analysis per pound of dry fuel . . B. T. U.
77. Calorific value by analysis per pound of combustible . .. . B. T U

Quality of Steam.

78. Percentage of moisture in steam . . . .
79. Number of degrees of super-heating. . . . .

Quantity of Steam.

80 Apparent weight of steam per hour... ....
81. Actual weight of steam per hour.... ....
82. Ratio of steam to air-supply. ....

Quantity of Air.

83. Percentage of moisture in air . . ..
84 Apparent weight of air per hour.... . ...
85. Actual weight of air per hour....... .. ..

Water.

86 Total weight of water used in jacket . ...
87. Number of heat-units carried out per pound of coal... . ...

Efficiency

88 Grate-efficiency of producer . . . .
89. Apparent hot-gas efficiency . . ..
90. Actual hot-gas efficiency. ....
91. Apparent cold-gas efficiency. . . ..
92. Actual cold-gas efficiency. ... .

Cost of Gasification.

93. Cost of fuel per ton delivered in producer room. . . . .
94. Cost per British thermal unit in gas .. ..

Poking.

95 Method of poking . ...
96. Frequency of poking . .. .

Firing

97. Method of firing. . .. .
98 Average intervals between firing.. . . . . . .
99. Average amount of fuel charged each time. . . . . .

Gas Analysis.

Per Cent

100 Carbon dioxide (CO_2) . . . .
101. Carbon monoxide (CO). . . . .
102 Oxygen (O) (as admixed air) .. . .
103. Hydrogen (H) . .. .
104 Marsh gas (CH_4) .. . .
105 Olefiant gas (C_2H_4) .. ..
106. Sulphur dioxide (SO_2) . . . .
107. Nitrogen (N) by difference .. ..

100 per cent.

108. Pounds moisture in gas per pound of coal. .. . .
109. Pounds soot and tar in gas per pound of coal .. ..
110. Calorific value of gas from analysis ....
111. Calorific value of gas determined with calorimeter . . ..
112. Specific heat of gas . ...
113. Figure of merit of gas . . ..
114. Carbon ratio $\frac{C}{H}$ .. ..
115. Volume of gas per pound of coal .. . .

I wish to express my thanks to Prof. N. W. Lord of the Ohio State University for criticisms and suggestions for this scheme.

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The following abbreviations have been used in the text:

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Eng. Lond., *The Engineer (London).*

Eng. Mag., *Engineering Magazine.*

Eng. News, *Engineering News.*

Eng. Rec., *Engineering Record.*

Eng. and Min. Jour., *Engineering and Mining Journal.*

Engng., *Engineering.*

Jour. Assn. Eng. Soc., *Journal of the Association of Engineering Societies.*

Engr., *The Engineer (Chicago).*

Jour. I. and S. I., *Journal of the Iron and Steel Institute.*

Jour. F. I., *Journal of the Franklin Institute.*

Mar. Eng., *Marine Engineering.*

Mem. Soc. Ing. Civ., *France*, *Memoires de la Société des Ingenieurs Civils, France.*

Pract. Eng., *Practical Engineer.*

Proc. Engs. Soc. of W. Pa., *Proceedings of the Engineers' Society of Western Pennsylvania.*

Proc. I. C. E., *Proceedings of the Institute of Civil Engineers.*

Proc. I. M. E., *Proceedings Institution of Mechanical Engineers.*

Trans. A. I. M. E., *Transactions of the American Institute Mining Engineers.*

Sci. Am., *Scientific American.*

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Power, April, p. 178. Illustration of suction-producer.

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Pract. Eng., vol. xxviii., p. 7. Illustrations and descriptions of recent forms of gas-producers.

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Engng., vol. lxxvi., September 25th, p. 420. Description and excellent illustrations of a Pierson gas-producer plant.

American Gas-Light Journal, March 30th. Gas for industrial purposes.

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Gas World, April. Cheap gas for motive power.

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Engng., vol. lxxvi., October 2d, p. 474. Description and illustration of Talbot mechanical gas-producer.

Engng., vol. lxxvi., November 20th, p. 696. Drawing and description of Pierson gas-producer.

Progressive Age, January 15th, p. 33. Description and illustrations of suction gas-producers for gas-engines.

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Proc. I. C. E., vol. clvi., p. 483. Abstract of article giving the summary of the results obtained in testing a suction gas-producer plant.

Zeitschr. d. V. D Ing., p. 157. Gives results of a suction gas-producer test; abstract of this is given in *Proc. I. C. E.*, vol. clvi., p. 483.

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Stahl und Eisen, vol. xxiii., p. 433–441–515–528. Elaborate discussion of the thermal reactions in the gas-producer and the action of the blast in detail.

Jour. I. and S. I., vol. ii., p. 582. Abstract of paper in *Stahl und Eisen*, vol. xxiii , p 433–441–515–528

Stahl und Eisen, vol. xxiii., p 693. Discussion by A. Ledebur of the changes that take place in the composition of producer-gas between the producer and the furnace.

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Iron and Coal Trades Review, vol. lxvi., p. 1644. Illustration and description of Duff producers and ammonia-recovery plant.

Transactions of the Civil and Mechanical Engineers' Society, vol. for 1902–1903, p. 53–68. Discussion of the advantages of the gas-producer as a power-generator.

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Braunkohle, p 358 and 373. Discussion of the use of brown coal in producers

Jour. Assn Eng. Soc., October, vol xxxi., p. 89. Description and illustration of the methods of making coal- and water-gas, with illustrations of gas-meters

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Power, September, p. 512 Brief description, with illustration of the suction gas-producer.

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Gas Power, October, p 3 Brief discussion of gas-producers.

Gas Power, November, p. 3 Suggestions for a marine-engine producer.

Gas Power, November, p. 4 Illustrations and descriptions of the Weber, Dunlop, Crossley, Bollinex, and Nagel producers

Gas Power, December, p. 16 Discussion of the advantages of gas-engine power-plants.

Suction Gas, by O. H. Haenssgen. A monograph devoted to the advantages of the suction gas-producer.

Eng. Rec., vol. l., October 1st, p. 406. Brief reference to the economy of an English gas-producer plant.

Eng. Rec, vol. l., December 3, p. 654. Description and illustration of a gas-producer plant.

Power, July, p. 425. Illustration and brief description of the Thwaite gas-producer for bituminous coal.

Power, August, p. 457. Illustration and brief description of a gas-producer used as a superheater.

Power, September, p 560 Brief discussion of gas-producer guarantees.

Power, September, p. 520 Description and illustrations of several gas-producers; gives summary of costs

Power, October, p 632 Description and illustration of the Thiesen centrifugal gas-washer

Power, November, p 696 Brief discussion of the transmission of producer-gas

Power, December, p. 752. Summary of comparative economies of steam- and gas-plants

Engr., February 1st, p 106, and March 1st, p. 177. Discussion of gas-power for central stations.

Engng, vol. lxxviii., November 18th, p 692 Brief discussion of bituminous coal-gas production.

Engng., vol. lxxviii, October 21st, p. 540. Illustration and description of a gas-producer designed to work on bituminous coal

Engng., vol. lxxviii., August 26th, p 285. Description of the testing of a Pierson suction gas-producer.

Engng., vol. lxxviii., September 2d, p. 295 Description and illustration of a Mond gas-plant.

Eng Lond, vol xcviii, August 12th, p. 151. Description and illustration of a Crossley gas-producer plant.

Eng Lond, vol. xcviii., November 4th, p 450 Description and illustration, with summary of test of a Pierson suction gas-producer.

Power, January, p. 1. Discussion of the "blast-furnace as a gas-producer;" describes plant and apparatus used in cleaning the gas.

Power, January, p. 50. Brief discussion of the "blast-furnace as a gas-producer."

Power, February, p. 72. Description and illustration of the Crossley gas-producer for bituminous coal.

Power, February, p. 100. Comprehensive and illustrated discussion of gas-power for central stations.

Power, April, p. 201. Brief description of a power-plant using wood in the gas-producers.

Power, June, p 362. Illustration and description of the Bollinckx suction gas-producer.

Les Gazogenes, by Jules Deschamps. This book is divided into 15 chapters, contains 432 pages with 240 figures, and gives a comprehensive discussion of the manufacture and use of producer-gas.

Oesterreichische Zeitschrift fuer Berg und Huettenwesen, September 24th. Discussion and description of the methods used in successfully gasifying peat, where the gas is to be used in gas-engines.

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Sci. Am. Sup., September 3d. Illustration and description of a Pierson gas-generating system.

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Power, December, p 789. Description and illustration of the Wile gas-producer.

The Electric Club Journal, vol. i., March, p. 65. Lecture on gas-power plants.

Engr., December 15th, p. 821. Illustration and description of producer-gas power-plant

Engr., October 15th, p. 717. Description and illustration of the Weber suction gas-producer.

Engr., July 1st, p. 450. Description and illustration of the Bollinckx suction gas-producer.

Engr., June 15th, p. 416. Description and illustration of the Otto gas-producer.

Iron Age, August 18th Description and illustration of the Thesian Centrifugal Gas-Washer.

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Proc. I. C. E., vol. clviii., p. 309. Brief discussion of the value of gas-producers.

Proc I. C E., vol. clviii., p. 320. Description of methods used in testing gas-producers, giving summary of efficiency, gas analysis and water consumption

Proc. I. C. E., vol. clv., p. 472 Abstract of article on gas-producer plants for heating.

Proceedings of the South African Association of Engineers, vol. i., p 131. Discussion of the evolution of the modern gas-power plant.

Iron and Coal Trades Review, vol. lxviii., p. 679. Gives comparison of the cost of power with water-gas, Mond gas, coal-gas and electricity.

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Eng. Lond., vol. xcvii., March 15th, p. 311. Brief description of a German producer-gas plant using brown coal briquettes for fuel.

Eng. Lond., vol. xcvii., April 8th, p. 370. Description and illustration of a Duff producer-gas plant using soft coal.

Producer-Gas, by Sexton. Extensive discussion of the physics and chemistry of the gas-producer.

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Engr., February 15th, p. 137. Description and illustration of the Letombe gas-producer.

Engr., February 1st, p. 107. Illustration and description of the Campbell suction gas-producer.

Engr., February 1st, p. 104. Illustration, with brief description of a Mond gas-producer plant.

Engr., January 16th, p. 89. Description, with illustration of the Fetu De Fize gas-producer.

Engr., January 1st, p. 27. Description and illustration of Crossley suction gas-producer.

Sci. Am. Sup., January 28th. Illustration and brief description of a Pierson producer-gas plant.

Sci. Am. Sup., February 4th, p. 24,320. Illustration and discussion of gas-producers for locomotive work.

Sci. Am., February 4th, p. 98. Brief discussion of gas-driven locomotives and ships.

Eng. News, vol. liii., January 19th, p. 78. Brief description of a Pintsch suction gas-producer.

Eng. Rec., vol. li., January 21st, p. 89. Same as *Eng. News*, vol. liii., January 19th, p. 78.

Power, January, p. 14. Brief discussion of the use of peat as a gas-producer fuel.

Engr., January 1st, p. 18. Extensive and detailed discussion of gas-producer systems; contains illustrations of the American, Baltimore, Nagel, Weber, Wile and Taylor producers.

Gas-Engine, January. Brief description with illustration of the Wile producer.

Eng. News, vol. liii., February 16th, p. 161. Illustration and description of Pintsch suction-producer.

Gas Power, January, p. 3. Illustration and brief description of the Pintsch suction-producer.

Gas Power, January, p. 5. Description and illustration of the Westinghouse producer for soft coal.

Sci. Am., February 18th, p. 139. Brief discussion of the gas-producer, with special reference to power-plants.

Pract. Eng., vol. xxxi., p. 203. Description and illustration of a suction gas-producer installed on a ship.

An Automatic Stock-Line Recorder for Iron Blast-Furnaces.

BY J. E. JOHNSON, JR., LONGDALE, VA.

(Lake Superior Meeting, September, 1904.)*

Of the many items of information necessary to the successful management of the blast-furnace, few are more important than knowledge of the location and movement of the stock-line:—whether the furnace is full and has been kept so; whether the stock is settling regularly or slipping; and, if slipping, how often it has slipped, at what times, and how far at each time. To obtain these data, a man is sometimes stationed at the top of a pair of mechanically-filled furnaces, simply to watch and gauge them by hand in the old-fashioned way. A more recent practice is the suspension of test-rods from ropes leading over pulleys to the ground-level, where the ropes are wound on small drums with graduated peripheries and provided with crank-handles, whereby the skip-man or some other person can quickly and conveniently gauge the position of the stock-line in the furnace. I believe the credit for this great improvement belongs to Messrs. McClure & Phillips of Sharon, Pa., who were, as far as I know, the first to apply it, and who have a patent for it. The valuable indications gained by application of the Uehling pyrometer to the down-comer are not to be ignored; but the information thus furnished is somewhat indirect, and there is no scale for the translation of "top-temperatures" into "feet down." Moreover, this apparatus, as a whole, is delicate, and the cost of installation and maintenance is high.

If the record furnished by the Uehling pyrometer is not in the most desirable form, the test-rods, on the other hand, give no record at all, except through the memory or notes of a man who, to say the least, is not gauging continuously, and who may omit to report an improperly low stock-line, if it be due to a fault of his own.

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* Manuscript not received in time for publication in vol. xxxv. of the *Transactions* (see *Trans.*, xxxv., p. xlv).

The object of the present paper is to describe an apparatus which, it seems to me, meets all these objections—being simple, durable and inexpensive, and giving, by its continuous and automatic action, accurate information concerning the stock-line for every minute of the day.

This device consists essentially of: (1) a test-rod suspended at its top by a chain, but normally resting on the stock and descending with it except when the bell is open; (2) a simple mechanism for lifting this rod out of the way of the in-coming stock at the latter period; and (3) an attachment for recording its motion on a reduced scale.

Before describing these parts in detail, certain special features of the furnace, to which this apparatus is now attached, should be mentioned.

1. The first is the charger, which has been described and illustrated in the recent paper by Mr. T. F. Witherbee, read at the Lake Superior meeting of the Institute.[1] It should be added, however, that the hopper now used is much deeper than that shown in Mr. Witherbee's paper.

The central off-take pipe for the gas makes it easy to place the test-rod so that it will hang vertically almost in the center of the furnace; while the special setting of the hopper, in conjunction with the type of bell used, makes any other position less convenient.

2. The furnace-plant is supplied with water under a natural head of about 60 ft., which is used to operate the bell, the cylinder being placed in a pit below ground-level, in order both to take full advantage of the head and to prevent freezing. Since it is not practicable to have the center of the cylinder under the end of the bell-lever, the rope running up from the former is carried over a sheave so as to give it the necessary direction. This sheave is supported on a pair of I-beams fastened to the furnace at one end and supported on a pipe-column at the other, about 8 ft. above the ground,—a convenient height for the support of the mechanism and the clock-case of the recorder.

The arrangement of the chain supporting the test-rod is clearly shown in Fig. 1. A pulley about 12 in. in diameter is

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[1] *Trans*, xxxv., 581, Fig 7.

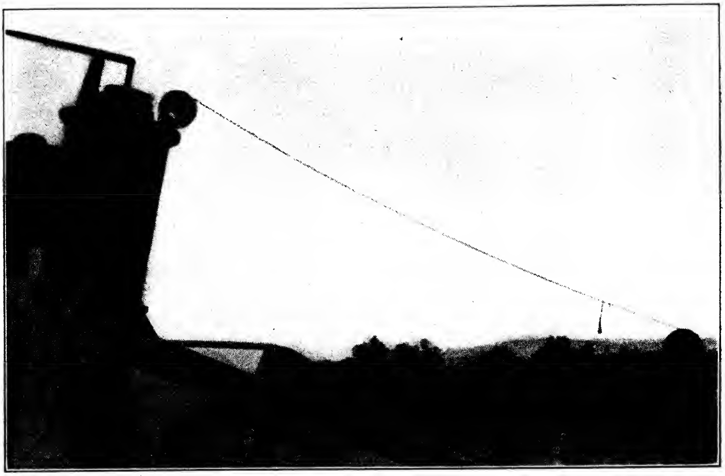


FIG. 1.—THE ARRANGEMENT OF THE CHAIN SUPPORTING THE TEST-ROD.

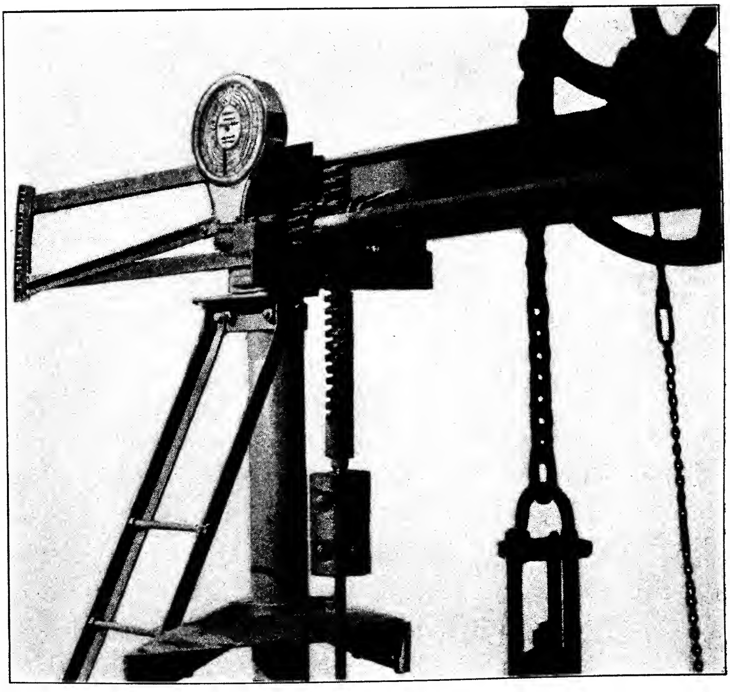


FIG. 2.—THE RECORDING MECHANISM AT THE BOTTOM OF THE FURNACE.

carried in a double bearing, resting on the cap of the central off-take pipe. The chain comes up from the test-rod (which is simply a $1\frac{1}{8}$-in. round iron bar, about 18 ft. long), passes through a hole in the cap and around the pulley supported thereon. Thence it goes to a similar pulley carried on a piece of 4-in. pipe held by a bracket on the side of the furnace and stayed to the filling-plates; and, passing over this pulley, it turns straight down. A short distance below the second pulley the chain is fastened to a piece of No. 10 wire which runs the rest of the way down. Chain was used at the top, because it was doubtful whether wire or wire-rope would stand the combination of heat and small pulleys. The chain is $\frac{3}{16}$ in. in size, and it has given no trouble whatever, though old and nearly worn out when first installed. Fig. 1 shows about half of the center-pipe at the left, and a portion of the bell-lever at the bottom of the picture. The photograph is not "square," having been taken from a rather precarious position on top of the fillers' house—the only available point.

The construction of the mechanism at the bottom is shown almost completely in Fig. 2, except that the operating-cylinder, being in the pit with the bell-cylinder, is of course out of sight. The wire from the test-rod is wrapped around a narrow drum, or double-flanged pulley, 36 in. in diameter with a 2.5-in. face (not shown in the figure); this is mounted next the end-bearing of a horizontal shaft about 7 ft. long, which carries, near its other end, a pinion about 4.75 in. in diameter. The extreme (left) end of the shaft enters the clock-case, as is described later.

With the pinion, meshes a rack a little over 2 ft. long, held in gear with the pinion by a guide-roller at the back, and carried from below by an extension of the piston-rod of the operating-cylinder.

The cylinder consists of a piece of 5-in. pipe about 30 in. long, bored out true inside and provided with plain screwed flanges. The piston is solid and has water-grooves. The cylinder is open below, and the top head, instead of a gland, has a rather long boss containing a renewable brass bushing, which is a working-fit on the piston-rod.

The valve of the bell-cylinder, operated by a wire rope running to the top of the furnace, is so arranged that, when it takes

the position necessary to allow the bell to be opened, water is turned into the recorder-cylinder and forces the piston down, which, through the medium of the rack and pinion, rotates the shaft carrying the drum and winds up the wire, thus raising the test-rod. The piston goes to the bottom and the test-rod is held at the top as long as the bell is open. When the bell-cylinder valve is reversed, the recorder-cylinder is opened to discharge, and the weight of the test-rod, acting with its greater lever-arm, pulls up the piston; the test-rod descending until it rests upon the stock at its new level. From this time on, the test-rod descends with the stock, unwinding the wire from the drum and raising the piston, until the bell is again opened and the whole cycle is repeated. The maximum stroke of the recorder-cylinder is about 2 ft., and the ratio of drum- and pinion-diameters being about 7.5 to 1, the maximum travel of the test-rod is about 15 ft., of which about a foot must be sacrificed in order to insure that the rod shall always be raised above the top of the stack and out of the way of the incoming stock.

The counter-weight clamped to the piston-rod extension (seen at the bottom of Fig. 2) keeps the slack out of the wire and takes up all lost motion in the rack and pinion. It also assists the cylinder to raise the test-rod, which would be a little too heavy for the cylinder alone, though about the proper size for the purpose.

The action of the recording-instrument is shown in Fig. 3. A clock-case with a 24-hour clock and dial (standard type of the Bristol Company) was procured, and a cast-iron support was made for it, which also carries the reduced end of the horizontal main shaft and a short piece of 1-in. shafting, which projects through into the clock-case and carries, at its inner end, a narrow segment of a gear, *A*, which meshes with the worm cut on the reduced end of the drum-shaft.

A pen, *B*, is fastened to the end of the small shaft and plays across the face of the revolving-dial, *C*.

To the rear end of the small shaft is fastened an arm about 4 ft. long (shown at the extreme left of Fig. 2), which serves the double purpose of taking up all back-lash in the worm-gear, and of indicating on an arc of a scale of 1 in. per foot how far down the stock-line is in the furnace, without requiring a close inspection of the dial for the purpose. This has proved to be a

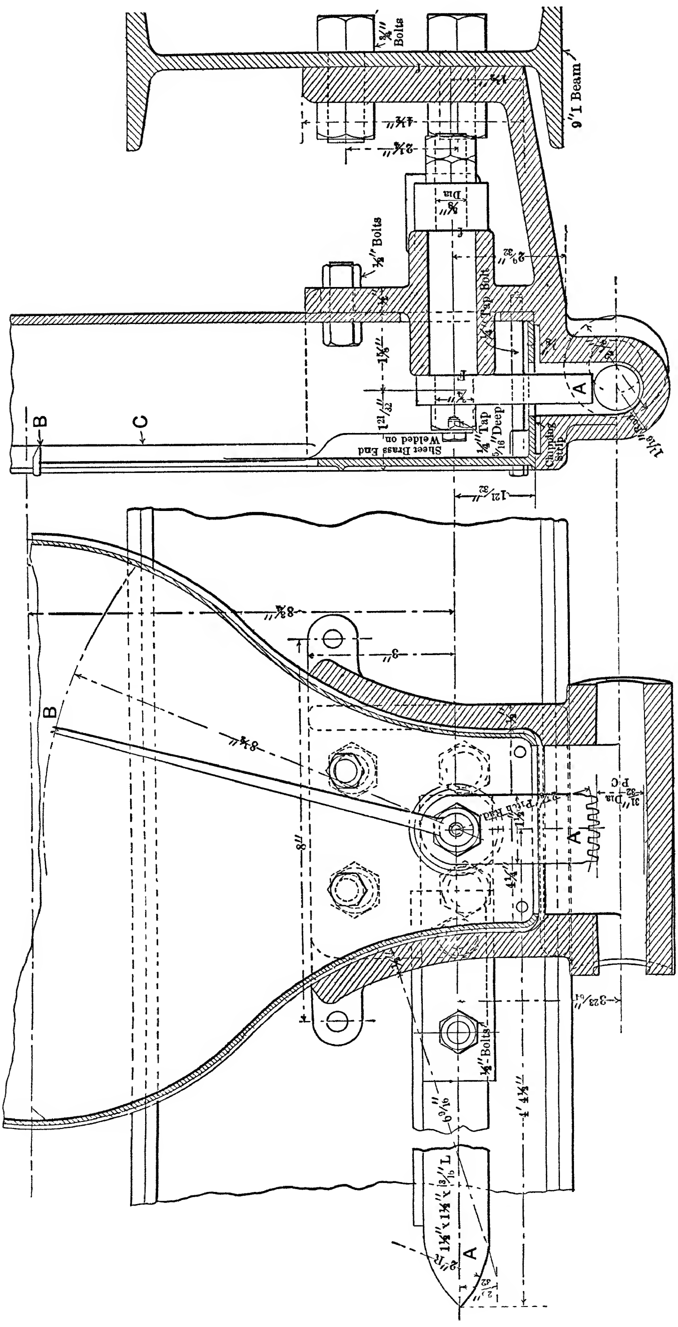


FIG 3.—BRISTOL'S PRESSURE-GAUGE ADAPTED TO THE AUTOMATIC STOCK-LINE RECORDER.

rather unnecessary refinement, as the lost motion could have been taken out of the gear by a much shorter lever, and the rack, or any part attached to it, furnishes a point of attachment for an indicator with a much more open scale and without any additional moving-parts. Moreover, the fillers have suspended from the chain at the top, as shown at the right in Fig. 1, a small bag filled with ore, so that it just goes to the outer pulley when the test-rod is at its uppermost position; and by watching this, they can tell when the furnace is "down" far enough to take another charge. This bag can be seen from all over the furnace-yard and serves as a first-class indicator—which goes to show that one does not necessarily foresee all the possibilities of his own devices, and that the most scientific engineering is not always the most effective.

The character of the charts is best shown by the reproduction of one of them, which is given in Fig. 4. The outer circle, marked "15" (feet), is 10 in. in diameter, and the circles representing feet are 0.155 in., or about one-seventh of an inch, apart; the odd figure being caused by circumstances of the individual case, into which it is not necessary to enter here.

The charts are put on at 10.30 a.m., which is the time for changing shifts, and also cast-time. Four casts per day are made, and the rapid descent of the stock at these periods, followed by the check for shutting-in, are very clearly shown in the record. The extremely regular descent of the stock-line at all other times is also obvious, and will move to envy some of the managers of hard-driven furnaces on Mesabi ores. The chart shown is not at all exceptional in this respect; in fact, if one had been available showing the slipping of the furnace, I should certainly have given it preference, for the sake of illustrating the action of the recorder under those conditions; but, during several months in which the apparatus has been at work, no such record has been made.

It may be explained that the zero-line of the chart has been taken at the height at which the furnace is as full as it can be filled without having the stock interfere with the bell; but the test-rod is raised higher than this, as explained above.

The completeness of the record is more noticeable after a little experience with the device than would be expected from a cursory examination of the chart. It is practically impos-

sible to "beat" the instrument, and make it show a good record, when a bad one was called for by the circumstances—a fact which the fillers themselves have come to appreciate.

The first night the machine was in operation, the night-shift were late coming out, and knowing that the machine was operated by the opening of the bell, the top-filler opened the bell without waiting to put anything on it, intending to show thereby

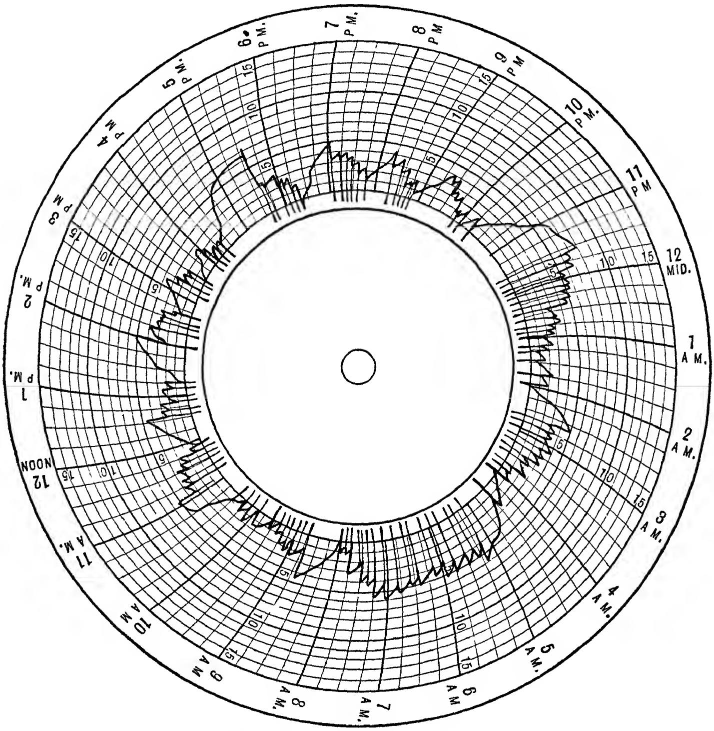


FIG. 4.—CHART FROM STOCK-LINE RECORDER AT FURNACE NO. 2, NOV 10 AND 11, 1904.

that they had already put up a charge. Of course the test-rod simply rose and descended again to its former level, indicating perfectly what had been done. The admonition delivered the next morning, with an accompanying explanation of the futility of such tricks, has served to prevent their repetition.

So far, there has been no cost for attendance and repairs. The man who oils the hoist- and bell-machinery once a day also puts a little oil on the working-parts of the recorder below.

(The pulleys on top are not oiled at all, on account of the dust.) The furnace-foreman puts in a new chart, winds the clock and puts ink in the pen once a day; and this is absolutely all the attention the apparatus receives. It was feared at first that, the top of the furnace being rather hotter than good practice permits, trouble might arise with the chain and the test-rod, and also, there being in the gas considerable zinc-oxide vapor, which builds upon whatever it touches, that this would cause trouble by clogging the chain, or perhaps adding to the weight of the test-rod; but these fears have proved groundless.

The circumstances under which the apparatus was installed at the plant described were, as the above statements show, less favorable than the average; yet no difficulty has been encountered hitherto, nor is any anticipated.

In the hope that the device described may be utilized by others, a few points as to its general design may not be amiss.

1. The cylinder should be of ample size to lift the test-rod and still have a good margin of strength; for if, after the falling-back of the stock subsequent to a slip, or from any other cause, the test-rod should be partly buried in the stock, the cylinder should be strong enough to pull it out.

2. The pipe for carrying the operating fluid—steam, air or water—to the cylinder should be small for the size of the cylinder or else well throttled, so that the piston will ordinarily travel at a moderate speed, thereby avoiding heavy jerks and inertia-stresses; while, at the same time, if the rod should be stuck in the stock after a slip, when the piston failed to move at first, the pressure would run up rapidly to the point at which it would be able to overcome the resistance and pull the rod out.

3. Some means for cushioning the piston at the end of its stroke should be provided. In the case described, this is accomplished by a helical spring around the piston-rod, which the nut on the latter strikes a few inches above the bottom of its stroke and compresses; but a better method would frequently be to close the lower end of the cylinder, and put a small vent for the escape of the air expelled by the downward stroke of the piston, at such a point that the piston would overrun it before reaching the end of its stroke, and would cushion on the entrapped air, very much after the manner of a Corliss "dash-pot," but more slowly.

4. The cylinder preferably should always be so arranged that the pressure will only be applied during the time that the bell is open, since this interval is short and the tightness of glands, pistons, etc., is of little consequence as compared with those which are under pressure most of the time. This can frequently be arranged by connecting the recorder-cylinder direct to one or the other end of the main bell-cylinder, or, in any case, by the use of a three-way valve operated by a connection from the main bell-cylinder valve.

5. Where the bell-cylinder is situated on the side of the stack, or at an inconvenient position for the recorder-dial, the only change required will be to put the cylinder and multiplying-shaft wherever required, and lead a wire to transmit the reduced motion of the shaft and test-rod to a convenient position for the clock-dial; the wire operating a lever directly connected to the pen-arm and being kept tight by a weight on its end. This arrangement is indeed simpler than the one here described.

6. The maximum travel of the test-rod is a subject requiring study, and the natural tendency is to make it as long as possible; but I believe that 20 ft. will be sufficient in most, if not all, cases. If the stock-line has been down more than this through any fault of the fillers, it is sufficient reason for drastic measures without knowing how much further it has been; and if it has slipped more than this, personal attention is demanded, and the added work of gauging by hand is very slight. On the other hand, the size of cylinder, ratio of gearing, and inertia of parts, all increase with increase of stroke; and the increased closeness of the scale on the chart, unnecessary for perhaps 99 per cent. of the time, is a distinct draw-back.

7. One point of minor importance is, that the slight jar on the clock-case due to the "bottoming" of the piston has a tendency to loosen the dial on the clock-spindle and may allow it to lag or hasten and thus spoil the accuracy of the time-record. The dial is only held by slight friction, and a very small jar is sufficient to loosen it. The remedy is to have a small thumb-screw through the central boss of the dial, or to have the boss split longitudinally and drawn together by a slightly conical screw-collar milled outside, the tightening of which causes the dial to have a firmer grip on the clock-spindle.

Several types of arrangement will probably be developed for the apparatus, and some of its details may be modified past recognition, if it should be as extensively applied as its usefulness seems to warrant; but in the great majority of cases, the local design will be a matter of small difficulty if the foregoing suggestions are followed.

Postscript.—The device described in the foregoing paper is the subject of U. S. Patent, No. 677,665, dated July 2, 1901, and issued to me. In my judgment, however, it would not be right to omit here a recognition of the issue to Mr. David Baker, May 14, 1901, of U. S. Patent, No. 674,112, for a stock-line indicator, operated by the lowering of the charging-bell. This patent contains no suggestion of a recording-attachment, and does not cover the use of an independent cylinder to operate the test-rod; so that my apparatus, in its present form, does not infringe in any way upon Mr. Baker's invention. This legal question, of course, is not to be discussed in the *Transactions* of the Institute; and I desire here only to acknowledge Mr. Baker's work, and to say that the first knowledge I had of the existence of his patent was after my own had been allowed. Whether, to this day, he has heard of mine, I cannot say. Evidently, we were working at the same time upon the same problem; he in Chicago, and I in Pittsburg.

Improved Method of Slag-Treatment at Argo.

BY HAROLD V. PEARCE, DENVER, COLO

(Washington Meeting, May, 1905)

The plant of the Boston and Colorado Smelting Company, at Argo, Colo., has not received special notice in technical or scientific publications for some time past. Dr. Peters[1] described the development of the reverberatory furnace used at Argo, but he dealt almost exclusively with the increase in size and the corresponding gain in capacity. Since the time of his description the changed conditions have led to a modification of the

[1] Modern Copper Smelting, 7th ed. (1895), pp. 445 to 454.

former smelting-practice, and this modification forms the basis of the present paper. No claim is made for personal originality in connection with these improvements, in fact, I expressly disclaim any such intention, since nearly every successful step in the development of the process now used at Argo has been suggested by Dr. Richard Pearce at various times during the past 12 years, though perhaps in a different manner of execution. These changes would undoubtedly have been made before, were it not that many problems of greater metallurgical importance and momentarily of more urgent need had to be solved first. At the time to which I refer, economic conditions demanded mainly an increase of capacity. Moreover, the determination and placing of exact losses in smelting were not so imperative then as they are now.

About three years ago, the time of my appointment to the management of the works of the Boston and Colorado Smelting Co., the great decline in the price of copper occurred; the Argo plant, in common with all others engaged in the copper-industry, lost heavily in the market-value of the stocks on hand of ore and furnace-products. Added to this was the unfortunate circumstance that the copper-supply of the Argo plant from general sources began to dwindle; in fact, it almost entirely ceased. About this time the smelting-plants in the western and northwestern States, on which the Argo plant for years had relied for a large proportion of its supply of copper in the form of matte, added converters and bessemerized their own copper-matte, thereby effecting a considerable saving in transportation- and smelting-charges. This local treatment of copper-mattes doubtless resulted from the development of the railroads, which simplified the question of fuel-supply and freight-rates, and, in justice to the former work at Argo, it should be said that there was no expression of dissatisfaction from those smelting-concerns with whom the company had been dealing for many years on mutually satisfactory terms.

In this way, what had always been in latter years a fairly lucrative portion of the business of the Argo plant, was practically lost. But to what proportion an abundant copper-supply entered into the economical necessities of the operations was neither realized nor accurately disclosed until this supply discontinued. A new system was then adopted in order to deter-

mine the exact losses or gains in gold, silver and copper; and these losses and gains were calculated for a number of years preceding, which showed that the only way to meet the altered conditions (since the smelting-charges could not be increased) was either to reduce the said losses in gold, silver and copper, or to make an increased gain where there had been a gain before; also to curtail operating-costs as far as possible.

The new situation required the adoption of radical changes. Operating-expenses were reduced more than ever before, but this economy alone could not counterbalance the greater deficiencies. New means had to be adopted to reduce losses in gold, silver and copper, which, under more flourishing circumstances, might have been regarded as unavoidable, but which had become a matter of vital importance and concern.

Following the research work, which was directed toward the placing and the reduction of smelting-losses, there came a readjustment of furnace-work, which has resulted in very important benefits and economies. It is not the purpose of this paper to publish comparative assays of slags before and after these particular changes in treatment went into effect, but to present an adequate idea of the savings thereby effected.

Although the lessons of the past have justified many improvements, every one knows the obstacles and difficulties which beset the manager who ventures to remodel a long-established smelting-plant such as the one at Argo.

About eighteen months ago, experiments were started having in view the cleansing of the ore-furnace slags. Owing to the large capacity of the ore-furnaces and the high degree of concentration effected in them, a very large quantity of slag was produced; and the saving of even a small portion of the values contained therein would amount to a very substantial aggregate in a year's time. These experiments were made in large crucibles in the refinery under the direction of my assistant, Mr. F. C. Knight, the object being to discover the effect of tranquil settling under various conditions of temperature and time; also the effect of adding different quantities of a matte-forming material, such as iron pyrite, to the charge of slag.

Formerly, the slag was divided into "clean" and "foul," and, before loading into railroad-cars, both classes were roughly broken, picked over by hand, and any lumps showing signs of

carrying prills of matte, were thrown back to be resmelted as foul slag. The remainder of the slag, which constitutes, of course, the larger portion of the skim, was loaded on cars and sent away as clean slag. The point to be observed in this practice, however, is that, although a large portion of escaping values was recovered in the foul slag, it was necessary to resmelt a considerable quantity in order to secure it. On the other hand, the so-called clean slag undoubtedly carried with it a certain quantity of foul slag. The assay of the sample of clean slag did not give a fair indication of the quantity of foul slag contained in a car-load, since the whole car-load of solidified slag was never crushed; but only a small ladle-sample was taken while it was molten. The sorting of slag was done in the open-air under all conditions of weather, and consequently it was impossible to make a perfect separation.

The object of these experiments was not so much to find out how the clean slag could be made cleaner, but how to treat the mixture of foul and clean slags as drawn from the ore-furnace during the process of smelting the charge. The general results of the experiments were, that, by the addition of a certain quantity of clean pyrite to the molten mixture of foul and clean slag, subsequently allowing the mixture to remain quiescent at a fairly high temperature for a short time, a small quantity of low-grade matte was precipitated to the bottom of the crucible and the superimposed slag was no longer a mixture of foul and clean slags, but a very clean slag indeed. No prills of metal could be discovered, and all the values in the foul slag that had been originally in the mixture were concentrated in the small quantity of matte at the bottom. The treatment of this matte on a large scale is a very simple matter, as compared with the former practice of handling and re-smelting all the foul slag.

These results, indicating in part, a solution of the problem, it was decided to build a small auxiliary reverberatory furnace for each of the large ore-furnaces, the idea being to skim all the slag from the latter into the smaller furnace, where the cleansing could be effected in a manner similar to that of the crucible experiments.

It had been the former custom at Argo to skim the slag from the large ore-smelting furnaces through two doors on either side, four skimmers being employed in this work. The first

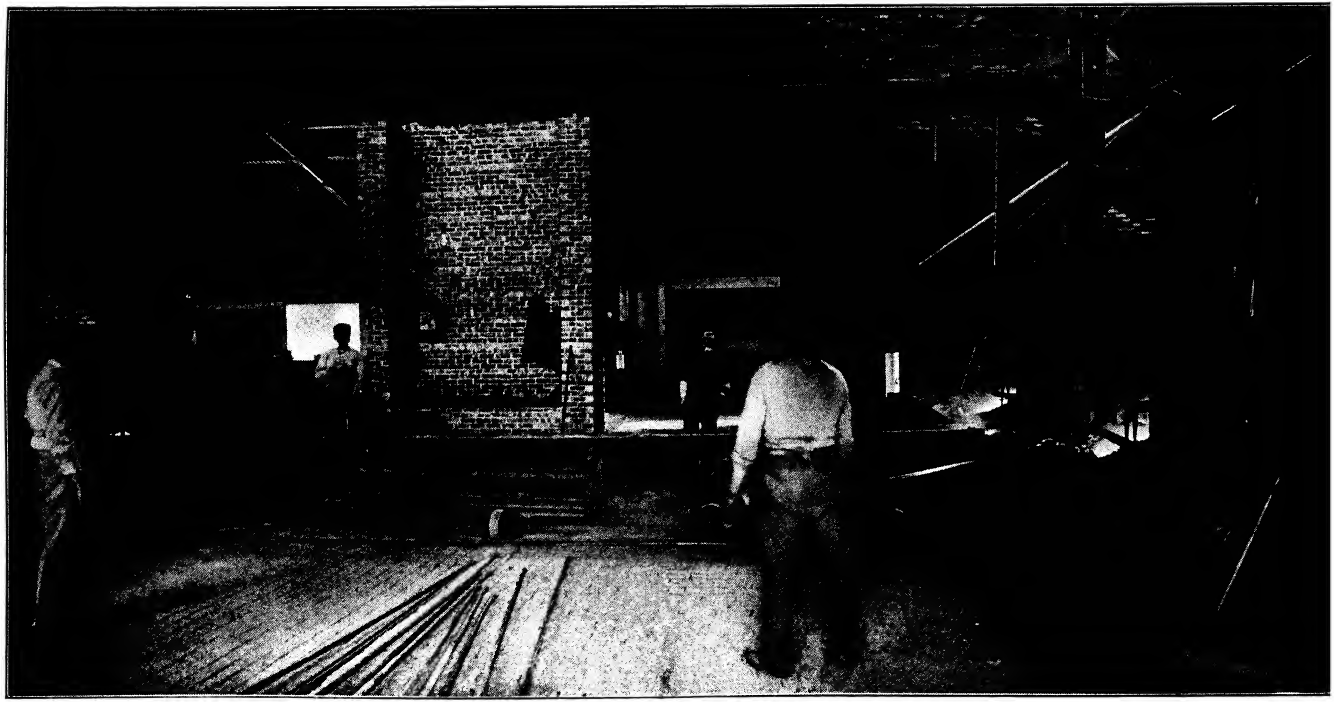


Fig. 1.—Tapping Slag from Ore-Furnace to the Auxiliary Slag-Furnace, which is Built at the Side, as Shown in Fig. 3.

[To face p. 92.]

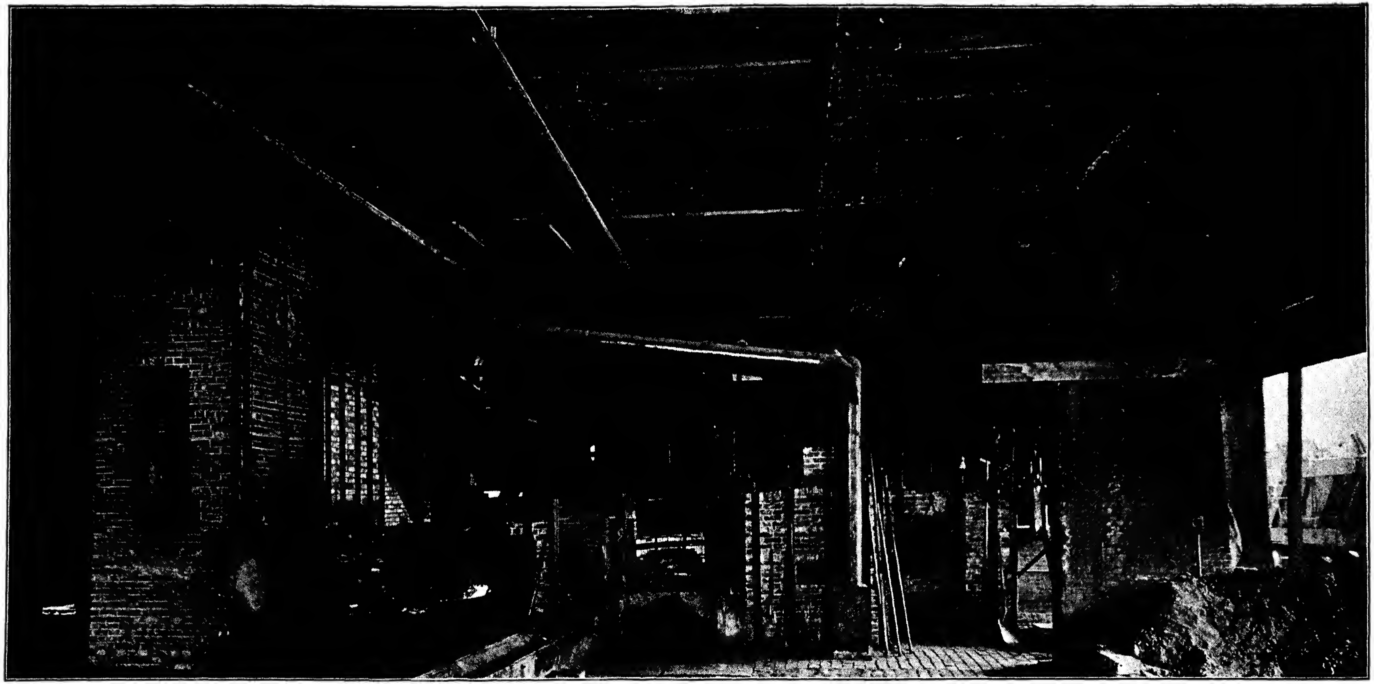


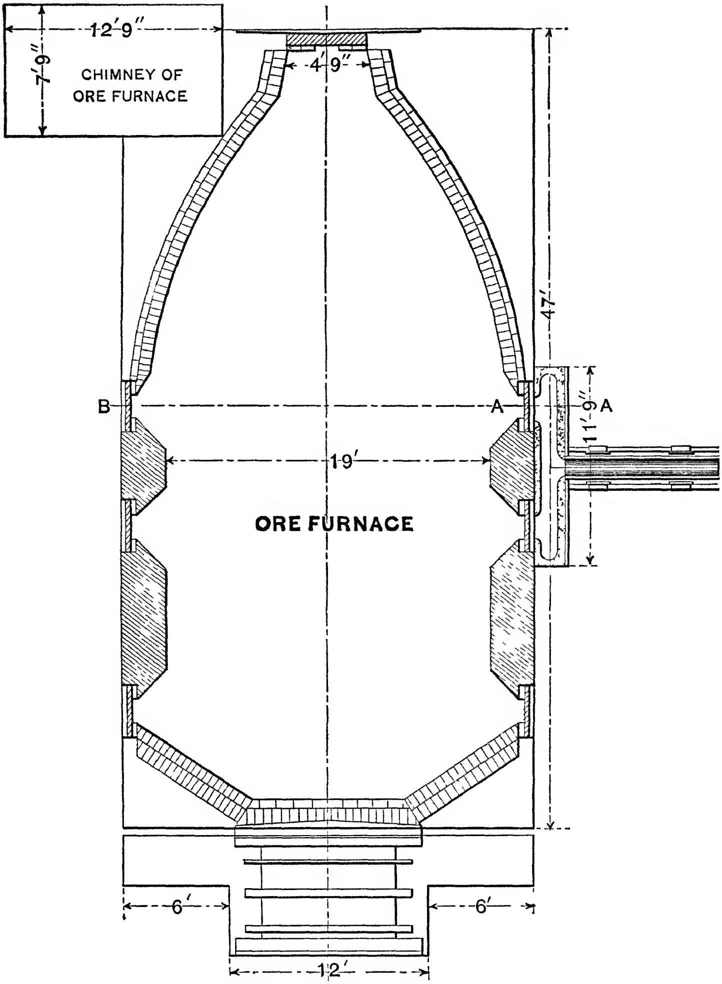
Fig. 2.—Auxiliary Slag-Cleaning Furnace, Ready for Tapping the Cleaned Slag; the Tap-Hole for Matte is at the Right and the Conical Pile Below the Side Door is a Charge of Sulphide Material.

auxiliary slag-furnace, as it is called, was built near the end of the ore-furnace, so that the slag skimmed from both sides could most conveniently be conveyed to it by means of iron spouts. The large quantity of slag, which became chilled in the spout leading from the more remote side, however, was a great drawback, and it was then decided to skim from one side only, the four skimmers taking turns at the rabbles. This arrangement seemed to work very well, and the later slag-furnaces were built by the side of the big ones, as shown in Figs. 1, 2 and 3.

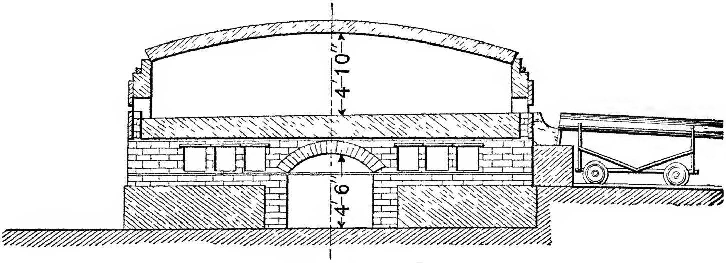
It was necessary to make many tests in order to determine the proper quantity of sulphide required to clean the slag on a large scale and under the different conditions of furnace-temperature. Many samples of slag, cleaned with varying quantities of sulphide and subjected to various periods of settling, were sent to an independent assayer, who was instructed to show no favor in the determination of slag-losses. In this way the most profitable conditions were ascertained, and, at the same time, assays were obtained that were absolutely reliable, since they were made by an impartial assayer who eliminated the personal equation that might have been induced by the desire for low results.

The time of "cleaning" a charge of slag in an auxiliary furnace is limited to the time occupied by the ore-furnaces in smelting a charge of ore. The slag-furnace must always be ready to treat the skim from the ore-furnace, which latter should not be kept waiting. About three hours and a half are usually required for the smelting of a charge of about 12 tons of ore.

The method of cleaning the slag is as follows: the large ore-furnace being ready for skimming, the spout, which connects it to the small auxiliary slag-furnace, is lowered in position. The slag-furnace fireman then stands ready to direct the flow of slag onto the hearth of the latter. The two side skimming-doors of the ore-furnace are removed, and four skimmers take turns at the skimming-rabbles, as before stated. After all the slag has been removed from the ore-furnace, that portion which became chilled in the spout is at once pushed into the slag-furnace and the door closed. The fireman then stokes the fire and maintains a moderate heat for about an hour, which suffices

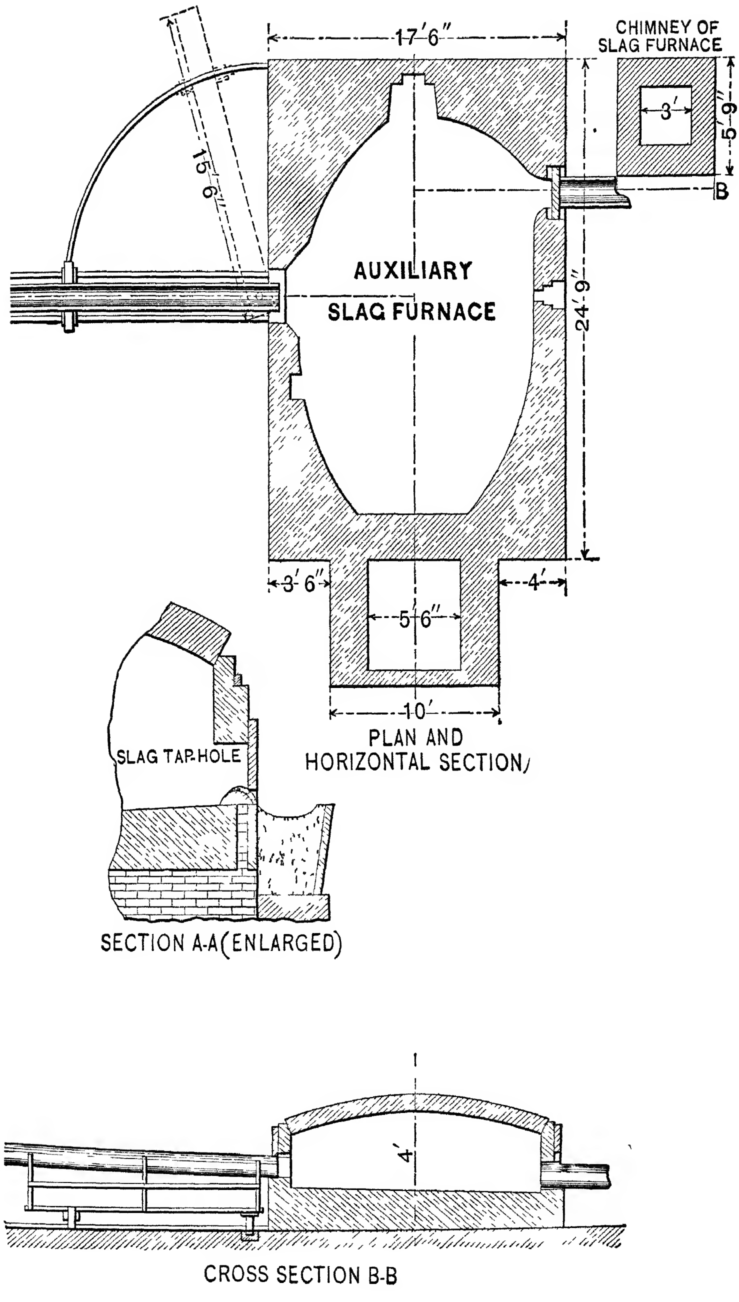


PLAN AND HORIZONTAL SECTION



CROSS SECTION B-B

FIG. 3.—PLAN AND SECTION OF THE ORE-



FURNACE AND ITS AUXILIARY SLAG-FURNACE AT ARGO.

to melt the "spouts," as the chilled slag in the spout is called. The side door is then raised and 1,000 lb. of sulphide, usually in the form of "tailings," are sprinkled evenly over the surface of the liquid slag. More heat is then applied and the settling and cleansing period begins, continuing for two hours or more, according to the requirements of the ore-furnace. In Fig. 3 it will be noted that the slag is tapped and not skimmed from the slag-furnace after it is cleaned, the hearth being built to slope rapidly toward the matte tap-hole, and the slag tap-hole being placed a short distance away at a slightly higher level. The level of the matte underneath is easily determined, and the slag is tapped almost down to this level. A "bay" or dam, consisting of clay and sand (see Fig. 3), is built up in the slag tap-hole of the slag-furnace, as the matte accumulates on the bottom, and the level of the slag rises in proportion. When ready to tap the slag, the temperature of the furnace is slightly raised and the slag-furnaceman tears down the dam gradually by means of an iron hook almost to the level of the underlying matte,—an action which allows the slag to flow out into sand molds conveniently placed to receive it. The slag tap-hole is then built up again with sand, and the furnace is ready to receive the next skim from the ore-furnace.

After treating about 20 skims of slag in this manner, the slag-furnace contains 4 or 5 tons of low-grade matte, which is then tapped through the matte tap-hole in the ordinary manner; but before letting out this matte, the small quantity of slag remaining on its surface (which is always left behind as a safeguard against the escape of small quantities of matte at the end of each out-flowing of slag) is skimmed through the front door of the furnace.

In describing the operating of the slag-furnace, it will be noticed that I have always used the terms "skimming" and "skims" in referring to the slag tapped from the ore-smelting furnaces, and in this connection a point arises which I judge is of great importance to those using reverberatory furnaces in lieu of, or in addition to, blast-furnaces.

It had long been a cherished hope that some day and somehow the laborious and somewhat painful process of skimming by the hand-manipulation of the venerable rabble might be dispensed with, but, for a long time, we were never able to sum-

mon up sufficient courage to try any of the several methods which have occasionally suggested themselves. The experience gained in operating the auxiliary slag-furnaces, however, furnished the necessary encouragement. The art of building up the bay or dam in the slag tap-hole of the small slag-furnace, and the control of the out-flow of slag therefrom, having been mastered, a fairly safe basis was thus afforded on which to attempt to regulate the flow of the slags from the large ore-smelting furnaces; moreover, the certain knowledge that any matte which might escape in the flow of slag from the ore-furnace would be caught by the auxiliary slag-furnace, removed any anxiety concerning the result of the trial, so far as losses were concerned. The trial made on one furnace was so eminently satisfactory that skimming, so far as the large ore-furnaces are concerned, has been discontinued.

The flowing of the slag takes place simultaneously through the two side-doors of the ore-furnace, and the bays or dams are built up precisely as in the slag tap-hole of the slag-furnace. Rabbles are used for stirring the charge and for what is called "trying" the furnace. It will be noticed in Fig. 1 that the side doors are suspended from the short arm of a lever, so that the skimmers (or rather "slag-tappers") themselves can raise the doors and regulate the opening by means of the slots which are arranged to engage the long end of the lever. This arrangement simplifies matters very much

Practical smelting-men will appreciate the full meaning of this method of tapping slag, when it is noted that lately, at three large ore-furnaces, the smelting of the charges had become finished at the same time; in other words, the slags of the three furnaces were ready to be skimmed or tapped at once. Although this occurrence is unusual, if it had happened under the old skimming-system, especially in hot weather, general despair and pandemonium would have resulted. Under the new conditions, however, two slag-tappers handled the three furnaces with perfect ease, casually strolling from one furnace to another, and keeping an eye on the out-flow of slag.

Figs. 1 and 2 show the operation of slag-flowing. Formerly two head-skimmers and two helpers were employed on each shift, but now the three large furnaces are handled by two head-skimmers in each shift. The economy here is apparent.

It may be mentioned that, as is also the case with the slag-furnaces, a small quantity of slag remains on the matte in the ore-furnace after the slag has been tapped. When this matte is ready to be tapped, say, once a week, the slag is skimmed off in the old way.

By the method of tapping the slag, a saving of thousands of dollars a year is made in rabble-iron alone There is, also, a saving of soap, which was formerly used to make the rabbles slide easily back and forth over the skimming-bar. Another item is the saving of elbow-grease, which can be better imagined than described.

I am not aware that tapping the slag, as described above, has been done elsewhere; possibly there is nothing novel in it; but for the benefit of those engaged in reverberatory smelting, to whom the use of auxiliary slag-cleaning furnaces would be of no particular benefit, it will be of interest to know that the use of the tapping-method, if properly carried out, results in a much cleaner slag than under the old method of skimming. In the practice at Argo, there has been a considerable decrease in the tenor of the matte resulting from the cleaning of the slag in the slag-furnaces since the tapping-method has been adopted.

A Summary of Lake Superior Geology with Special Reference to Recent Studies of the Iron-Bearing Series.*

BY C. K. LEITH, MADISON, WIS

(Lake Superior Meeting, September, 1904.)†

CONTENTS

* Published by permission of the Director of the United States Geological Survey.

† Manuscript not received in time for publication in vol. xxxv of the *Transactions* (see *Trans.*, xxxv., p. xliii)

General Geology of the Lake Superior Iron-Bearing and Copper-Bearing Series.

The presence of large and rich iron- and copper-deposits has made a knowledge of the geology of the Lake Superior region necessary for purposes of exploitation and exploration.

The ores of the region are contained in rocks of pre-Cambrian age, which, for most of the country up to recent years, have usually been referred to as "crystalline schists" or "crystalline complex;" and regarded principally as a metamorphosed basement-unit upon which the sedimentary rocks, beginning with the Paleozoic, were laid down. In the Lake Superior region this pre-Cambrian complex presents an unusual variety of rocks with determinable relations. It has been possible, with the large expenditures which the magnitude of the iron-mining industry warrants, to work out their stratigraphy to a larger degree than has been possible in almost any other area of pre-Cambrian rocks.

The real complexity of Lake Superior geology, the confusion of names and the multiplicity of reports covering small parts of the region, are such, that interested persons, other than geologists directly engaged in the work, may well hesitate to attempt to comprehend the geology of the region as a whole. The following paper is a somewhat elementary outline of the geology of the Lake Superior region with special reference to new developments not yet covered in published reports.

Geological information concerning the region has been gathered by mining companies, and by the geological surveys of Michigan, Wisconsin, Minnesota, Ontario, Canada, and the United States. Perhaps in no other part of the country have the mining-men themselves spent such large sums in purely geological work. This has made possible the publication of reports and maps by the State and Government surveys in much less time and at far less cost than would have been otherwise possible. The U. S. Geological Survey is the only organization which has covered all of the region on the United States side of the boundary, and, as its reports include most of the information gathered by the mining-companies and State

organizations, special reference is made to these reports. The work of the Survey was begun in the early eighties in charge of Prof. R. D. Irving, and has been continued since 1888 by Dr. C. R. Van Hise and his assistants. The results of their work appear in a series of detailed monographs and maps on each of the principal producing ore-bearing districts.[1] A final general monograph on the Lake Superior region, accompanied by revised maps of each of the districts and a general geological map of the region, is now in preparation. The features sketched in the present paper will be fully described in that volume.

Geological work has been much less detailed in the Canadian portion of the Lake Superior region, largely due to the fact that the ore-bearing districts, thus far discovered, have not seemed to warrant such large expenditures for geological work as have been made in the United States portion of the region. The Michipicoten district is the only ore-bearing district which has been mapped and described in any considerable detail,[2] although much has been written on the general geology of the north shore.[3]

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[1] The Copper-Bearing Rocks of Lake Superior, by R D Irving, *Monograph V*, *U S. Geological Survey* (1883)

The Penokee Iron-Bearing Series of Michigan and Wisconsin, by R D Irving and C. R Van Hise, *Monograph XIX*, *U S Geological Survey* (1892)

The Marquette Iron-Bearing District of Michigan, by C R Van Hise and W. S. Bayley, *Monograph XXVIII.*, *U. S. Geological Survey* (1897)

The Crystal Falls Iron-Bearing District of Michigan, by J. M. Clements and H. L Smyth, *Monograph XXXVI*, *U. S. Geological Survey* (1899).

The Mesabi Iron-Bearing District of Minnesota, by C K. Leith, *Monograph XLIII*, *U S Geological Survey* (1903).

The Vermilion Iron-Bearing District of Minnesota, by J M Clements, *Monograph XLV*, *U S Geological Survey* (1903).

The Menominee Iron-Bearing District of Michigan, by W S Bayley, *Monograph XLVI*, *U S Geological Survey* (1904).

See also ·

Correlation Papers—Archean and Algonkian, by C. R Van Hise, *Bulletin No. 86*, *U S Geological Survey* (1892).

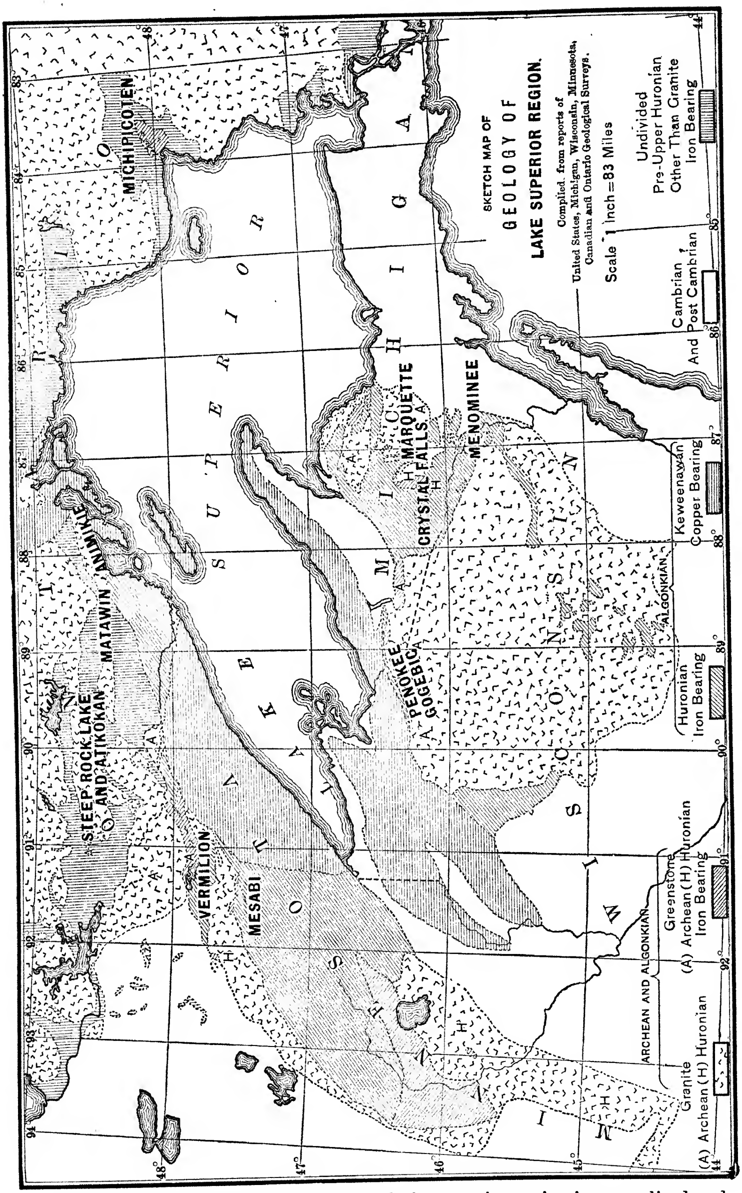
The Iron-Ore Deposits of the Lake Superior Region, by C R. Van Hise, *21st Annual Report*, *U S. Geological Survey*, Pt III, pp 305–434

Principles of North American Pre-Cambrian Geology, by C. R Van Hise, *16th Annual Report*, *U S Geological Survey*, Pt I., pp 571–874.

[2] The Michipicoten Iron-Ranges, by A. P Coleman and A B Willmott. *Geological Series, University of Toronto Studies*, pp 39–151 (1902).

See also *Report of the Bureau of Mines*, Ontario, 1902, pp. 152–185.

[3] See *Reports* of Ontario and Canadian Geological Surveys.



This sketch-map of the geology of the Lake Superior region is generalized and modified from a general geological map of the Lake Superior region, on a scale of ten inches to the mile, compiled by C. R. Van Hise and C. K. Leith for publication in a final general monograph on Lake Superior geology in preparation for the U. S. Geological Survey.

The ore-bearing districts themselves, comprising but a small portion of the Lake Superior region as a whole, are the areas in which the fullest successions of pre-Cambrian rocks are exposed; the intervening areas are less well-known. It has been possible to correlate, with reasonable certainty, the major geological units, although the geology of each of the districts has been worked out in large part independently; but because of the considerable, less well-known areas separating the closely studied districts, it is difficult at the present time completely to unify the geology of the region (see map on opposite page).

The succession in the Lake Superior region, as given in Table I., will serve as a guide in the summary given below.

The Archean or Basement Complex.

The oldest rocks in the Lake Superior region have considerable lithological complexity. It was formerly supposed that they were largely granites and gneisses with but subordinate amounts of basic igneous rocks, but it is now known that they include large quantities of basic igneous rocks and also two or more sedimentary formations. The abundant rocks are granites, gneisses, syenites, acid porphyries, basalts, gabbros, peridotite, mica-schists, hornblende-schists, and chlorite-schists (some of the schists resulting from the alteration of the above-named rocks), jaspers, iron-ore and slates. It is not possible fully to state the stratigraphic relations of these rocks, but so far as positive evidence goes, certain of the basalts with associated schists, known collectively by the terms greenstones and green schists, are the oldest; that associated with them, and perhaps in part later and above these, are the iron-formation and slate; and that intrusive into both the basal greenstones and sedimentary rocks are considerable masses of acid igneous rocks. The basic igneous rocks, commonly referred to as greenstone and green schist, with their associated slates and iron-formation, are called "Keewatin," (following Lawson and the report of the International Committee.) The acid rocks, including granites, gneisses and acid schists, are called "Laurentian."

One of the conspicuous features of the greenstones and green schists of the Keewatin is the presence of ellipsoidal, spherulitic and pyroclastic phases, indicating their essential surface-volcanic origin. The basement upon which they were deposited

TABLE I.—*Correlation of Pre-Cambrian*

		Mesabi District	Penokee-Gogebic District	Vermilion District	Marquette District
ALGONKIAN	KEWEENAWAN (Copper-bearing)	Great basal gabbro and granite	Gabbros, diabases, etc	Great gabbro	
	UPPER HURONIAN (Iron-bearing)	*Mesabi Series* Virginia formation (upper slate) Biwabik formation (iron bearing and productive) Pokegama formation (quartzite and quartz-slate)	*Penokee-Gogebic Series* Tyler formation (upper slate) Ironwood formation (iron-bearing and productive) Palms formation (quartz-slate)	*Animikie Series* Upper slate formation Gunflint formation (iron-bearing, but non-productive)	*Upper Marquette* Michigamme formation (slate) (locally replaced by Clarksburg volcanic formation) Contains productive iron-ores near base Ishpeming formation, consisting of two members Bijiki schist (in western part of district) and the Goodrich quartzite containing productive detrital ores at its base
	MIDDLE HURONIAN (Iron-bearing)				*Middle Marquette* Negaunee formation (iron-bearing and productive) Siamo slate Ajibik quartzite
	LOWER HURONIAN	Granite intrusive in lower formations Slate-graywacke-conglomerate formation	Bad River limestone formation (cherty limestone) Quartzite	Intrusives Knife slate Agawa formation (iron-bearing, but non-productive) Ogishke conglomerate	*Lower Marquette* Wewe slate Kona dolomite Mesnard quartzite
ARCHEAN OR BASEMENT COMPLEX	LAURENTIAN (Intrusive into Keewatin)	Granites and porphyries	Granite and granitoid gneiss	Intrusive granites, porphyries and greenstones	Granite, syenite Palmer gneiss
	KEEWATIN (Iron-bearing)	Greenstones, hornblende-schists and porphyries	Green schists and fine-grained gneiss	Soudan formation (iron-bearing and productive) Ely greenstone, an ellipsoidally-parted basic igneous and largely volcanic rock	Kitchi schist and Mona schist, the latter banded, and in a few places containing narrow bands of non-productive iron-bearing formation Peridotite

Series of the Lake Superior Region.

Crystal Falls District	Menominee District	Keweenaw Point	Michipicoten	Other Parts of Ontario North of Lake Superior
		Lower, Middle and Upper Keweenawan Interbedded lavas and sediments grading up into sandstones		Interbedded sediments and traps along Lake Superior shore
Michigamme formation, containing a productive iron-bearing horizon not separated in mapping for much of the district	*Upper Menominee* Hanbury formation, mainly slate, bearing in lower portions calcareous slates, etc., containing siderite and iron oxide Vulcan formation, consisting of three members Curry member (iron-bearing), Brier slate and Traders member (iron-bearing)			Animikie series of northwest shore comprising iron-formation overlain by slate
Hemlock formation (basic volcanic) Negaunee formation (iron-bearing)	Negaunee formation doubtfully present			Undivided pre-Animikie sediments, mainly graywackes, slates and conglomerates, much metamorphosed
Randville dolomite Sturgeon quartzite	*Lower Menominee* Randville dolomite Sturgeon quartzite		Basic eruptives Acid eruptives Doré conglomerate	
Granite	Granites and gneisses.		Granites and gneisses	Granites and gneisses
	Quinnesec schist (?)		Eleanor slates Helen formation (iron-bearing and productive) Wawa tuffs Gros Cap greenstones	Greenstone and Iron formation, similar to that of Vermilion district of Minnesota

has not been found. It may be certain of the granites, which have been called Laurentian, but the granites for the most part are certainly intrusive into the Keewatin. It is an interesting fact, then, that the oldest rock in the Lake Superior region (and perhaps the oldest pre-Cambrian rock with definitely determined age in the country) is of surface-volcanic origin, with an unknown basement upon which it was deposited.

The nature and distribution of the Archean rocks in the different parts of the region are discussed in subsequent paragraphs.

Michigan and Wisconsin.—The predominating rocks of the Basement Complex in Michigan and Wisconsin are granites and gneisses which appear both north and south of the Marquette district; within the Crystal Falls district, and to the east of it; to the north and south of the Menominee district; and south of the Penokee-Gogebic district. These granites and gneisses show a variety of characters and are certainly not all of the same age, although so far as known they antedate the Algonkian rocks. One of the acid units on the south side of the Marquette district has been discriminated under the name "Palmer gneiss." The character of this rock is such as to suggest that it may represent, in part, a much-altered acid sediment. It is certain that rocks mapped as Palmer gneiss are sedimentary, but such sedimentary rocks really belong to the Algonkian, and have been included in the Palmer gneiss because of errors in mapping. How far into Wisconsin these Basement Complex granites and gneisses extend is not known. In north-central Wisconsin, granites of apparently similar characters have been found to be later than the Basement Complex, and it is not known where, in the great granitic area extending from central Wisconsin to the State boundary, to draw the line between the granites of the Basement Complex and later granites.

Taking up the Keewatin rocks of Michigan and Wisconsin, we find on the north side of the Marquette district a considerable area of peridotite and areas of green schist, including chlorite and mica-schist, resulting from the alteration of basalts, some of them presenting evidence of surface-volcanic origin and perhaps of deposition under water. Where finely schistose, the rocks have been called the "Mona schists," and where giv-

ing evidence of derivation from surface-volcanics, they have been called "Kitchi schists." Associated with the green schists of the Marquette district are several small areas of jasper and carbonate rocks, formerly supposed to be of the nature of ferruginous vein-material, but now believed to represent a sedimentary iron-formation, infolded or interbedded with the greenstones and belonging with the Basement Complex.

Green schists of similar character, occurring both north and south of the Menominee district, have been known as the "Quinnesec schists." To the west of the Menominee district along Pine river, the apparent extension of the Quinnesec schists is found to be unconformably beneath the Upper Huronian sediments. They are assigned to the Keewatin because of their lithological similarity to the Keewatin green schists in the Marquette district and because of their occurrence on the outer edge of the Huronian area of the Menominee district, which is thought to have a synclinal structure. The northern area of Quinnesec schists has been shown by recent field-work to be probably intrusive into the Upper Huronian. The same is true of the green schists on the Brulé river to the west. These, therefore, should no longer be assigned to the Keewatin but to the Upper Huronian or Keweenawan.

South of the Penokee-Gogebic district are two areas of green schist, including mica-schist, chlorite-schists, and hornblende-schists, which have been known respectively as the eastern and western green schist areas. Between the Gogebic and Crystal Falls districts, surrounded by Huronian sediments, are several areas of greenstone and green schist, which probably belong with the Keewatin, but which, because of their isolation, do not allow of their structural relations and age being determined.

Central and Eastern Minnesota.—In Minnesota, along the Minnesota, Mississippi and Snake rivers, are areas of granite, gneiss, hornblende-schist, mica-schist, diabase, gabbro, etc., which have been in the past referred to the Basement Complex. Hall, however, concludes that certain of the schists have resulted from the intrusion of granite into the Huronian sediments, as typically developed at Carlton and Cloquet; and thus that most of the acid igneous rocks are of Algonkian age. Certain of the massive diabases, running eastward from the Mississippi river, are older than the granites, and lithologically

resemble the Keewatin greenstones in the Mesabi and Vermilion districts. These are accordingly mapped as Keewatin, while the granites are mapped as Algonkian.

Mesabi District, Minn.—The Archean is represented by several comparatively small areas of greenstone and green schist, comprising ellipsoidal basalt, hornblende-schist, chlorite-schist and mica-schist, intrusive into which are granite porphyries in small quantity.

Vermilion District, Minn.—In this district, the Archean is mainly represented by great areas of ellipsoidal basalt, in some cases showing surface-textures, occurring in great oval-shaped areas surrounded by sediments. Closely associated with these greenstones, in relatively small lenses and bands, are the rocks of the productive Soudan iron-formation, including jaspers, iron-ore and slate. The relation of the iron-formation and greenstone have been much studied, but with only partly positive results. The iron-formation is almost certainly sedimentary because of the association with slates and because of the similarity to other known sedimentary iron-formations of the Lake Superior region; yet, with the exception of a trivial amount of slate at one or two places, the jaspers rest with sharp contact against the greenstone without intervening fragmental material. Mining-operations, together with the surface-distribution of the iron-formation, indicate that the iron-formation, in many cases at least, rests on top of the greenstone and has been infolded with it: but for many of the iron-formation bands, there is little opportunity to determine the relations; and it has been thought probable that some iron-formation bands may be interbedded with greenstone-flows. In this connection it is interesting to note that at Schreiber bay, on the north shore of Lake Superior, well-bedded Animikie iron-formation rests on granite without intervening fragmental sediments, although a short distance away this material is found. Intrusive into the Vermilion greenstones and iron-formation are granite-porphyries and massive granites. The latter occur for the most part in the great area lying north and east of the Vermilion range. Immediately adjacent to the range they are known as the Vermilion, Trout, Burntside, Basswood, and Saganaga granites. Along the contact of the greenstone there are considerable belts of hornblende-schist which are taken to rep-

resent the contact-effects of the intrusion of the granite. This granite presumably extends northward into Canada and connects with the granites mapped as Laurentian (in old sense of acid pre-Cambrian) by the Canadian geologists; but again, information is not available which will allow the drawing of boundaries between granite belonging to the Basement Complex and granite of later age, some of which (and perhaps a considerable amount) appears in the Canadian districts to the north.

Michipicoten District.—The Archean of this district presents close similarities to the Archean of other parts of the Lake Superior region, especially in the Vermilion and Marquette districts. It consists of greenstones with ellipsoidal and other surface-structure; of tuffs, both basic and acid; of an iron-formation; and of slate,—all intruded by granites and gneisses. The iron-formation is believed to be the counterpart of that seen in the greenstone in the streets of Marquette, in the Vermilion district, and elsewhere in the region.

Other Points on the North Shore of Lake Superior.—Greenstones, with associated iron-formation, similar in many respects to those of the Michipicoten and Vermilion districts, are known in many areas in Ontario. They are typically developed in the Mattawan, Atikokan, and Steep Rock Lake iron-ranges, northwest of Lake Superior

Algonkian.

The fullest succession of the Algonkian system comprises four unconformable sedimentary series, all of them being associated with igneous rocks. The three lower series are collectively referred to as the Huronian, and the upper series as the Keweenawan. All are unconformably above the Basement Complex and below the Potsdam for this district, but in no single district are all of them represented. While there are similarities between the Huronian series of the different districts, which are believed to warrant their correlation, the differences are such as to make it desirable to discuss the Huronian succession of the individual districts separately, in order to avoid the impression of definiteness or finality of correlation which would inevitably tend to obscure, or perhaps distort, the facts. The Keweenawan series is essentially a unit for the region and it is so described on a subsequent page.

Marquette District, Mich.—In the Marquette district, all three of the Huronian series are present. They are locally called the Lower Marquette, the Middle Marquette and the Upper Marquette series. Heretofore the Huronian has been mapped as comprising two divisions,[4] the Upper Marquette and the Lower Marquette series; but the discovery, by Prof. A. E. Seaman, of a great unconformity within the former Lower Marquette, proves the presence of three series. The Lower Marquette series, as now defined, consists of three formations, the Mesnard quartzite, the Kona dolomite, and the Wewe slate, varying from 1,200 to 3,000 ft. in thickness. The Middle Marquette series includes, from the base up, the Ajibik quartzite, the Siamo slate, and the Negaunee iron-bearing formation, varying from 1,900 to 3,000 ft. in thickness. The Negaunee iron-bearing formation carries the important iron-ore deposits of the district. The Upper Marquette series includes the Goodrich quartzite, the Bijiki schist, and the Michigamme slates. The Bijiki schist, appearing principally in the western part of the district, is taken to be partly equivalent in age to the Goodrich quartzite, which occurs especially in the central portion of the district; but where the two come together, the Bijiki schist is above the Goodrich quartzite. Both are conformably overlain by the Michigamme slate. There are iron-ore horizons at the base of the Goodrich quartzite, at the base of the Bijiki schist, and at the lower horizon of the Michigamme slate; those at the first horizon mentioned being largely detrital and derived from the underlying Middle Marquette series. Both the Lower and Middle Marquette series are intruded by basic igneous rocks in the form of dikes and bosses. The Upper Marquette, also, is interbedded in the central part of the district with a series of fragmental basic volcanics known as the Clarksburg formation. The Lower Marquette series is the most folded and metamorphosed, the Upper Marquette series the least; the Lower Marquette series is the thinnest of the series, the Upper Marquette the thickest; the Lower Marquette occupies the least area, the Upper Marquette the greatest. The unconformities between the Middle and Lower Marquette and between the Upper and Middle

[4] *Monograph XXVIII*, *U. S. Geological Survey*, p 3

Marquette series are, in each case, evidenced by basal conglomerates and by truncation of the underlying series. It cannot be said, at present, which of the two unconformities is the more important.

The structure of the sedimentary series is that of a fan-shaped or abnormal synclinorium with east-west axis and westward pitch. Faulting plays a subordinate part, but still is important. The nature of the faulting is illustrated in the Teal Lake range of the Marquette district and the Teal Lake type of faulting has been found to explain the shape and distribution of certain of the ore-deposits.

The Crystal Falls District, Mich.—In the Crystal Falls district the Huronian rocks have been divided in the U. S. Geological Survey map and report[5] into the Upper and Lower Huronian, corresponding to the old division of Upper and Lower Marquette series for the Marquette district. In the Crystal Falls district the Lower series has not been found to be divided by unconformity, but it includes formations similar to those of the two lower divisions, now known, of the Huronian of the Marquette district, and therefore the three-fold classification will be here adopted. The Lower Huronian consists, from the base upward, of the Sturgeon quartzite and the Randville dolomite, varying from 600 to 1,600 ft. in thickness. The Middle Huronian consists of the Negaunee iron-formation. Cutting and resting on both series is the Hemlock formation, consisting largely of basic volcanics. The Upper Huronian comprises the Michigamme slate-formation, containing an iron-bearing horizon not separated in mapping for much of the district.

There is practically no evidence of unconformity between the Hemlock volcanics and the Upper Huronian slates, the existence of the break being largely inferred in the Survey report from the difference in lithological character and the apparent close relations of the Hemlock volcanics with the Lower Huronian sediments. There is also no decisive evidence that the iron-formation of the Crystal Falls and Amasa areas, mapped and described as Upper Huronian, may not really be Middle Huronian (Negaunee). It seems to be nearly connected, through magnetic lines, with the iron-formation mapped as Negaunee in the eastern part of the district.

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[5] *Monograph XXXVI*, *U. S. Geological Survey*, p. xxv.

The series have been folded into complex folds with trend varying from the north-south to the east-west. The closer folds in the northeastern part of the district are nearly north-south; in the central part northwest-southeast; in the eastern and southeastern parts nearly east-west. All of these folds have steep pitches.

Menominee District, Mich.—The classification has been, in the past, Lower Menominee and Upper Menominee, separated by unconformity,[6] but as the formations are similar to those of the Marquette district a three-fold classification is here adopted. The Lower Menominee series comprises the Sturgeon quartzite- and Randville dolomite-formations, in all respects similar to formations of this name in the Crystal Falls district, and similar, respectively, to the Mesnard quartzite and the Kona dolomite of the Lower Marquette series of the Marquette district. The Middle Menominee series has not been found, although iron-formation pebbles, supposed to represent it, are found in the conglomerate at the base of the next overlying series. The Upper Menominee series comprises the Vulcan formation, consisting in ascending order of three members, (*a*) Traders iron-bearing formation, (*b*) Brier slate, (*c*) Curry member (iron-bearing), and above this the Hanbury slate, bearing, in lower portions, calcareous slates, siderite and iron oxide. The thickness of the series varies from 2,650 to 3,650 feet.

In the Menominee district, the structure has been mapped as that of a northwest-southeast trending synclinorium with a minor anticlinal roll bringing up the older formations in the central portion of the district. However, attention is directed to the fact, that the Lower Huronian, which ought to appear on the south side of the trough, is here missing, and the synclinal structure is inferred rather than actually observed. The absence of the Lower Huronian here has been explained by the overlapping of the Upper Huronian slates. If the Quinnesec schists to the south should be shown to be Lower Huronian intrusives, rather than Keewatin, then we might look for the southern edge of the Menominee synclinorium almost anywhere to the south, and the suggestion is made that the quartzite to the south of the Quinnesec schists in Wisconsin may really constitute the southern margin of this trough.

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[6] *Monograph XLVI., U. S. Geological Survey*, p. 39.

Penokee-Gogebic District, Mich. and Wis.—In the Penokee-Gogebic district, representatives of the Lower and Upper Huronian series with intervening unconformity are found. The Middle Huronian seems to be lacking. The Lower Huronian series comprises a lower quartzite overlain by a cherty limestone-formation (Bad River limestone) similar respectively to the Mesnard quartzite and the Kona dolomite of the Lower Marquette series. The Upper Huronian series (the Penokee-Gogebic series) comprises, from the base up, the Palms quartz-slate formation, the Ironwood iron-bearing formation and the Tyler slate-formation, doubtfully aggregating 13,300 ft. in thickness. Much the largest portion of the district is occupied by the Upper Huronian rocks, principal in mass among which being the slate. Intrusive into the Upper Huronian are diabase dikes, probably of Keweenawan age. The principal series of the district, the Upper Huronian, strikes in general east-northeast and dips 65° to the north.

Area East of Penokee-Gogebic District.—In the broad triangular area between the east end of the Penokee-Gogebic district and the Marquette, Crystal Falls and Menominee districts, is a great slate-formation constituting the upper division of the Upper Huronian series. In isolated areas within this slate, appear iron-formations, productive at Iron River and Florence. There appear, also, basic volcanics and older Huronian sediments, the correlation of which is doubtful.

Area South of Menominee District.—Extending southwest from the Menominee district, into north central Wisconsin, is an area of quartzites with indefinite limits, which include considerable masses of igneous material of unknown age.

North Central Wisconsin.—Here, granites occupy about 75 per cent. of the area of crystalline formations, but associated with it are greenstones, rhyolite, schist, slate, quartzite and conglomerate, believed by Weidman to represent at least two, and perhaps three, of the Huronian series. The results of his work will be published in a bulletin of the Wisconsin Geological and Natural History Survey.

Chippewa River and in Barron County, Wis.—In this region are quartzites and conglomerates, containing fragments of chert and jasper, which again are similar to those of the Huronian of Michigan, but which cannot be assigned to any one division

of the Huronian. Their lithological similarities are with the Upper Huronian.

Central Minnesota.—In the vicinity of Carlton, Cloquet and Little Falls, and extending to the southwest, is a considerable area of well-banded graywacke and slate, similar in all respects to the undivided Lower Huronian of the Mesabi and Vermilion districts to the north. To the south and southwest are certain hornblende- and mica-schists which Hall[7] believes to be the result of metamorphism of the graywacke and slate by intrusive granite, which appears in that direction; but some of them are doubtless metamorphosed igneous rocks.

Near Dam lake, south of Kimberly, is a quartzite exposure, which has been correlated with the Upper Huronian of the Mesabi district.

Along the Minnesota river are quartzites similar to the Huronian quartzites of Michigan. Their lithological similarities are with Lower Huronian quartzites, but because of their isolation they are so assigned only tentatively.

Mesabi District, Minn.—In this district, a two-fold classification of the Huronian series is possible. The upper division corresponds with the Upper Huronian of Michigan and Wisconsin, while the lower division might be equated with either or both of the Lower and Middle Huronian of Michigan, so far as present evidence goes. It will be here referred to as the Lower Huronian, following the Survey report.[8] The unconformity between the Upper and the Lower series is, as usual, a great one. The Lower Huronian consists of conglomerates, graywackes and slates, with bedding and schistosity standing vertically and striking east-northeast. It occurs in but small areas, and is intruded by the Giant's Range granite, which constitutes the main topographic feature of the Mesabi range. The Upper Huronian (Mesabi or Animikie series) comprises from the base up, the Pokegama quartzite-formation (200 ft. thick), the Biwabik iron-bearing formation (1,000 ft. thick) and the Virginia slate-formation (great, but unknown, thickness). This series rests on the south slope of the Giant's range, strikes east-northeast, dips for the most part southerly and southeasterly at angles varying from 5° to 20°, and is gently cross-folded, the

[7] Hall, C. W., *Bulletin U. S. Geological Survey*, No. 157.

[8] *Monograph XLIII., U S. Geological Survey*, pp. 201, 202.

axes of the cross-folds pitching in the direction of the general dip noted. Intrusive into this series at the east end of the district are Keweenawan granite and basic igneous rocks, the latter in the form of sills, laccolites and dikes. Here the series is highly metamorphosed.

Vermilion District, Minn.—Here again, only a two-fold classification of the Huronian is possible, these divisions corresponding very closely in lithology and structure with the same divisions of the Mesabi district, although varying greatly in relative areas. The Lower Huronian sedimentary series is composed of conglomerate, slate and graywacke, occupying large areas in this district. Usually the series appears in belts between, and surrounding, the cores of greenstone belonging to the Basement Complex. The schistosity and bedding stand nearly vertical and strikes east-northeast. This series is intruded by granite masses, such as the Giant's Range, Cacaquabic Lake, White Iron Lake and Snowbank Lake granites. The Upper Huronian series occurs only in the east end of the district, where the eastward continuation of the Upper Huronian of the Mesabi district laps diagonally and unconformably across the east end of the Vermilion district. The Upper Huronian here is similar in all respects to that of the metamorphosed Upper Huronian of the east end of the Mesabi district proper.

International Boundary and North Shore of Lake Superior.—Extending from the east end of the Vermilion district in the vicinity of Gunflint lake, eastward to Pigeon point, and northeastward to the head of Thunder bay on Lake Superior, and thence in discontinuous areas past Nepigon bay, is a great area of Upper Huronian or Animikie rocks, similar in all respects to the Upper Huronian rocks of the Mesabi district and of the south shore, except that the iron-bearing and quartzite-members are not so well developed and the series is more largely intruded, parallel to the bedding, by Keweenawan sills of basic igneous rock, known as the Logan sills. Lower Huronian sediments have been recently found to appear in a narrow belt north of the Animikie rocks to the east of Thunder bay.

Michipicoten District.—Rocks of Lower Huronian age, consisting of conglomerate, graywacke and slate, associated with basic and acid eruptives, similar in all respects to the Lower Huronian series of the Vermilion district, are here present.

Keweenawan.[9]

The uppermost of the four members of the Algonkian series of this region, the Keweenawan, is a series of coarse, fragmental sediments, sandstone and conglomerate, with small amounts of limestone, interbedded and cut with basic and acid igneous rocks, including gabbro, diabase, porphyrite, amygdaloid, felsite, quartz-porphyry, etc. For the district as a whole, the igneous rocks are more abundant in the lower portions than in the upper portions. Accordingly, a three-fold division has been made, from the base up, into gabbros, interstratified lavas and clastic rocks, and clastics. On the north shore, however, eastward from Port Arthur, sediments in considerable volume constitute the lowest part of the series. Many of the basic and acid rocks are surface flows. The diabase-flows frequently pass in their upper parts into porphyrites and amygdaloids. Many flows are porphyritic or amygdaloidal throughout. The beds of quartz-porphyry and felsite are abundant in certain districts, but usually have no great lateral extent. While a single basic or acid flow may be traced but a little way, frequently a set of flows of the same general character may have a great extent and thickness. But even the sets of flows cannot be regarded as general formations for the whole of the Lake Superior basin. No tuffs have as yet been found.

The Keweenawan rocks occur for the most part around the west end of Lake Superior with a general synclinal structure, the rocks of the series on the south side of the series dipping somewhat steeply to the north, and those on the north side dipping less steeply toward the south.

On the south side of the lake, the principal development of the series is on Keweenaw point, whence the series gets its name. Here are located the important copper-bearing mines of the Lake Superior region. The copper occurs as metallic copper in amygdules of the flows, and replacing parts of both the igneous and clastic rocks, especially the conglomerates. The upper part of the series here is almost clear sandstone.

The Keweenaw point series rests on the southeast against

[9] This description follows somewhat closely, except for certain new developments, the one given by Van Hise in his paper, The Principles of North American Pre-Cambrian Geology, 16*th Annual Report U. S. Geological Survey*, Pt. I., pp 571–874.

Upper Cambrian sandstone, there being along the contact a marked fault-plane, which has obscured the relations of the two. While there has been difference of opinion on the interpretation of the facts, it is the prevailing view that a pre-Cambrian fault-scarp with downthrow toward the east here existed, against which the Cambrian sediments were deposited; and that subsequent to their deposition further faulting in the same direction broke and deformed the Cambrian rocks near the contact.

To the southwest of Keweenaw point, the Keweenawan series comes in contact with the Huronian of the Penokee-Gogebic district,—in the central part of the district with the slate, and at the east and west end of the district with the iron-formation of the Upper Huronian series, indicating that, prior to the deposition of the Keweenawan series in this district, there had been folding of the Upper Huronian series in such a way as to expose the east and west ends to erosion; that here the slate had been eroded away, and that subsequently the Keweenawan rocks were deposited against the truncated edges of the series. The lowest rocks are, for the most part, igneous flows dipping in much the same direction as the Upper Huronian, but in or at certain places in the lower horizons conglomerates are taken to represent the base of the series.

Still farther to the west and southwest, the Keweenawan series extends through Douglas county, Wisconsin, into Minnesota. The characters of the series are much the same as on Keweenaw point. Copper-deposits are present, but of disputed value. On the northwest side of the tongue of the Keweenawan projecting southwest into Minnesota, there is again a contact with Cambrian sediments along which there has been marked faulting, tending to obscure the relations. The Cambrian rocks for the most part are turned up and broken along the contact.

On the northwest shore of Lake Superior, the Keweenawan series consists almost wholly of the lower igneous portion. The most important member is a great gabbro mass extending from Duluth to the international boundary, in a great crescent with concavity toward the lake, having a width for much of the distance of from 20 to 25 miles. The rock has everywhere a typical granitic structure, and includes, lithologically, very magnetitic gabbro, olivine-gabbro, normal gabbro, and masses of basic

feldspar rocks or anorthosite. The relations of these varieties to one another have not always been determined. Much of the gabbro has a laminated arrangement of the mineral particles, and, corresponding with this arrangement, the rock has a bedded or sheeted appearance. Overlying this gabbro mass are flows of both basic and acid eruptive rocks, ending diagonally against the gabbro, and, near the international boundary, associated with these flows are conglomerate (Puckwunge conglomerate) masses, probably interbedded with the Keweenawan flows. The flows also have crescentic distribution to the southeast of the gabbro. On the northwest the Keweenawan gabbro overlaps the east end of the Mesabi district, lapping diagonally across all the members of the Upper Huronian series onto the Lower Huronian granites. Near Gunflint lake and eastward along the international boundary, and northeast beyond Port Arthur, basic sills of the Keweenawan have penetrated the Upper Huronian series parallel to the bedding. The metamorphic effects of the Keweenawan igneous rocks on the Upper Huronian series have been most profound, producing cordierite-hornstones from the slates, amphibole-magnetite rocks from the iron-formation, and very coarsely crystalline quartzites from the quartzite. Moreover, by minute injection and transfer of material at the contacts, other peculiar metamorphic rocks have been developed at Pigeon point, Gunflint lake, and elsewhere. Near Loon lake, northeast of Thunder bay, the basal horizon of the Keweenawan is a coarse conglomerate resting in turn on Upper Huronian and Lower Huronian formations and carrying fragments of them.

The relations of the Keweenawan to the underlying rocks are somewhat complex because of the combined sedimentary and igneous nature of the series. On the south shore, as already indicated, the relations are, for the most part, confused by faults. In the Penokee-Gogebic district, conglomerates of doubtful horizon may represent the base of the series. At various places on the north shore of Lake Superior, as on the northeast side of Thunder bay, the lowest member of the Keweenawan series is a conglomerate containing fragments of the underlying rocks, which here consist both of granite and greenstone and Upper and Lower Huronian sediments. The conglomerate is associated with sandstone and limestone. To-

gether, the sediments are in considerable mass. To the west of Port Arthur, they diminish in amount, and in the Mesabi, Gunflint Lake, and international boundary areas, the lowest rock of the Keweenawan is the Duluth gabbro. It was formerly supposed that the Duluth gabbro represented a great basic flow, which was poured out at the beginning at Keweenawan time, covering the truncated edges of the Animikie and underlying series. It is now believed that it represents a great intrusion, which occurred in late Keweenawan time, between the interbedded sedimentary and igneous flows of the Keweenawan series, and the underlying pre-Keweenawan rocks. The following characteristics favor this view,—coarse texture of the mass; lack of surface volcanic textures; apparent connection with the Logan sills which are intruded into the Upper Huronian sediments; minute injection of gabbro material into the iron-formation in the vicinity of Akeley and Gunflint lakes; profound metamorphism which it has caused in the adjacent rocks; diagonal ending of overlying Keweenawan flows against the gabbro, which, on the theory of extrusive nature of the gabbro, would require erosion, or tilting between the gabbro and the flows; and, finally, the fact that, for at least a part of the district, the Keweenawan period was inaugurated by the deposition of sediments rather than by igneous activity.

The Keweenawan is the thickest of the series about Lake Superior. Its average was estimated by Irving on Keweenaw Point to be 35,000 ft., but estimates by subsequent observers are usually less.[10] This vast quantity of material does not, of necessity, mark a period longer than, or perhaps even one as long as, the Lower Huronian or Upper Huronian, since the greater part of it is of igneous origin, and doubtless accumulated rapidly. The lava-flows in their extent and thickness are to be compared with the great volcanic plateaus of the far West rather than with local volcanoes, such as Vesuvius, or the local volcanoes of the Upper Huronian and Lower Huronian. No volcanic fragmental material associated with the lavas has as yet been discovered.

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[10] Burwash estimates thickness on Michipicoten Island at 36,000 ft in a recent paper, received since above was written, The Geology of Michipicoten Island, by E. M. Burwash, *University of Toronto Studies, Geological Series, No. 3*, Toronto, 1905.

The fact that erosion was contemporaneous with eruption for much of Keweenawan time is to be noted. Certainly, when the period was well inaugurated, much of the Lake Superior basin was frequently, if not normally, below the sea or near tide-water. Many of the eruptions may have been sub-aqueous. Here and there volcanic masses of such magnitude were built up as to rise above the water, and upon such areas the sea at the base, and the air and rain above, immediately began their course of destruction. The acid and more viscous lavas may have formed the more prominent elevations, and thus the attack was here more vigorous. This may partly explain the predominance of the acid pebbles in the conglomerates. Prof. Seaman has called attention to the manner in which similar acid slags puff up, and suggests, that because of this, the acid lavas may have yielded more readily to the waves.

This great volcanic period was doubtless one of unstable equilibrium, the lithosphere falling here and rising there. The final resultant of all the movements was the production of the Lake Superior syncline. This synclinal movement affects not only the Keweenawan rocks, but also the lower series, and in areas in which the unconformity between the Upper Huronian and the Keweenawan is not great, there is such a likeness in strike and dip of the two series as to suggest at first that the two are conformable. It is only as the contacts between them are followed for some distance, and the Keweenawan is seen to be now in contact with one member of the Upper Huronian and now with another, that an unconformity between the two is perceived.

What proportion of the Keweenawan has accumulated before the Lake Superior syncline began to form, it is impossible to say. Possibly the larger foci from which the great extrusions of lava occurred were in the area now covered by water. Probably sinking went on contemporaneous with volcanic action, as is commonly a result of the upbuilding of mountainous masses of volcanic material. This suggestion, if true, would partly explain the apparent absence of volcanic fragmental material, which naturally would accumulate near the foci. Nowhere are the Keweenawan rocks so closely folded as to give them a secondary structure, or a much altered character.

The diabases, gabbros and diorites, so extensively intruded within the Lower Huronian and Upper Huronian rocks, in part

at least, are, in all probability, of Keweenawan age; but this statement is difficult to prove.

General Notes on Structure and Distribution of the Lake Superior Series.

For the region, as a whole, it is difficult to make a brief statement adequately covering the complex structure and distribution of the pre-Cambrian series; but consideration of a few general features may aid in fixing the reader's ideas of the general geology of the region. By mapping under one symbol all greenstones and under another symbol all granites, whether of Archean or Algonkian age, the granite- and greenstone-areas may be easily remembered in their general distribution (see Fig. 1). By so doing we may avoid also the necessity of drawing boundary lines between granite and greenstone of different ages in the parts of the Lake Superior region in which a separation has not been satisfactorily made. For stratigraphic purposes, the granite- and greenstone-areas may be practically eliminated from our consideration. There then remain principally the pre-Cambrian sedimentary series with interbedded volcanics, which are of primary importance in comprehending the general stratigraphy of the region. These are grouped about the west half of Lake Superior. The west end of Lake Superior consists of an eastward-pitching synclinorium of Keweenawan rocks with gentle southerly dips on its north limb and fairly steep northerly dips on its south limb, the Keweenawan series there fringing the west half of the lake. The next underlying series, the Upper Huronian, to a less extent takes part in this synclinal structure and has a distribution consonant with such structure, that is, bordering the outer edge of the Keweenawan areas. In detail, the structure of the Upper Huronian is far more complex than that of the Keweenawan series; and in Michigan, in the triangular area extending eastward from the Penokee-Gogebic district and fingering out in the Marquette, Crystal Falls and Menominee districts, the Upper Huronian appears in a series of rolls, which apparently have no counterparts in the Keweenawan series. The Lower and Middle Huronian sediments occupy but limited areas as compared with the other Algonkian rocks. In large part they were folded before Upper Huronian or Kewee-

nawan time, and their strikes and dips give no evidence that they form a part of the Lake Superior synclinal, but they appear near the complex outer border of the Lake Superior synclinal as constituted by the Keweenawan and Upper Huronian rocks, or, in other words, with a major distribution required by the general synclinal structure of the lake. In the Marquette, Crystal Falls and Menominee districts, the distribution is more complex. The Archean rocks again give no evidence in their strikes and dips of participation in the Lake Superior synclinal structure, but they also border this synclinal as constituted by the Upper Huronian and Keweenawan rocks.

It has been possible to explain the major structure and distribution of the Algonkian series on the basis of folding. But recent study has tended to show that faulting has played a greater part than had been supposed, although still a subordinate part. A system of definitely recognizable strike and dip-faults has been worked out in the Marquette district by Prof. Seaman, and the effect of these faults on the distribution and structure of the ore-deposits has been noted in at least one of the mines. Presumably, further work will show more of such features. In the Gogebic district important faults, both across and parallel to the iron-formation, have been found to have an important bearing on the distribution and structure of the ore-deposits. In the Mesabi range, a normal fault, inferred but not observed during the preparation of the Geological Survey report on the Mesabi range, has been exposed by further mining-operations in the Biwabik mine. Strike-faults of considerable magnitude also occur in the Animikie iron-range east of Thunder bay.

As a result of the closer folding of the lower series in the region as a whole, as compared with the higher ones, and as a result also of the intrusion into the lower series of deep-seated, highly metamorphosing, igneous masses to a greater extent than into the higher series, the lower series shows, in general, more profound metamorphism than the higher ones, although all of them are altered.

General Notes on the Correlation of the Lake Superior Series.

The Keweenawan series of Lake Superior region is recognized by all as approximately a unit. The same may be said

of the series here called the Upper Huronian series (Animikie of the north shore), although it is possible that the iron-formation in the Menominee district, now mapped with the Upper Huronian, will have to be separated from it and placed in the Middle Huronian series. Through Michigan, the great connecting formation of the Upper Huronian is the black slate, which occurs in each of the districts and in the area to the west. While the similarity of the iron-formation of the Menominee and Crystal Falls district to the Negaunee or Middle Marquette iron-formation has been recognized, and the structure of the region together with magnetic observations, seems to indicate their connection, it has not been possible to find any break between the Menominee and Crystal Falls iron-formations and the great overlying slate-member; and because of this, the iron-formation has been mapped with the black slate, which is Upper Huronian, if anything in the district is Upper Huronian.

The rocks called Lower and Middle Huronian show much wider diversity of lithology and corresponding greater difficulty in correlation than the overlying series. The two series have been precisely separated only in the Marquette district; but in the Crystal Falls, Menominee and Gogebic districts the sedimentary formations beneath the Upper Huronian are so similar to formations of the Lower and Middle Marquette series, that there seems little doubt of their substantial equivalence. On this basis, both the Lower and Middle Huronian are represented in the Crystal Falls district; the Lower Huronian is represented in the Menominee district, and perhaps also the Middle Huronian, if the iron-formation proves here to belong; and the Lower Huronian is represented in the Gogebic district. In the Vermilion, Mesabi, Carlton and Cloquet districts, are sediments recognized by all as belonging to one series below the Animikie or Upper Huronian series, and above the Archean. This series is not similar in lithology to the Lower or Middle series of Michigan and Wisconsin. The term Lower Huronian, which has been applied to it, signifies only that the series is like the Lower Huronian series of Michigan and Wisconsin in being beneath the Upper Huronian. The Minnesota Lower Huronian may represent either, or both, of the Middle and Lower Huronian series of Michigan. This lower series of sediments in Minnesota has been usually referred to by the Minne-

sota Survey as the Upper Keewatin series, although not sharply separated in mapping and including members which the U. S. Geological Survey had not included in its Lower Huronian. The conglomerates and slates of the Michipicoten and other districts of Ontario are correlated with the Lower Huronian series of the Vermilion district of Minnesota, on the basis of their striking similarity in lithology, structure, and in relations to the Archean.

The discovery by Professor Seaman that the Lower Huronian series of the Marquette district really comprises two great series, which are here called the Middle and the Lower Huronian series, has led to a revision of the correlation of the Lake Superior and Lake Huron series. Prior to this discovery, emphasis had been placed on the dual nature of the series, and this had involved a correlation of the undivided Lower and Middle series of Michigan with the lower series of the Original Huronian district on the north shore of Lake Huron, and a correlation of the Upper Huronian series of the Lake Superior region with the upper of the two unconformable series on the north shore of Lake Huron. It now seems probable that the Upper series of the Lake Superior region is lacking in the Lake Huron area, and that the two series there found should be correlated with the Middle and the Lower series of the Marquette district. The importance of this change from the standpoint of correlation is a very great one.

The correlation of the rocks here called Archean or Basement Complex has few doubtful features in the region, although the nomenclature is not generally agreed upon. The basal position of certain granites in Michigan and northern Minnesota has been recognized by all. But in the past, the U. S. Geological Survey had included with the basal granites certain of the granites which they now include in the Lower Huronian, thus coming more nearly into accord with Minnesota and Canadian geologists, who have held that more of the granites are later intrusives than belong to the Basement Complex.

There are many similarities in the Keewatin greenstones and green schists of the Michigan, Wisconsin, Minnesota, and Ontario districts, perhaps the most striking being the presence of ellipsoidal structures and pyroclastic phases. There is also similarity between them in their association with sedimentary

slate and iron-formation material. In previous work, the U. S. Geological Survey has supposed the iron-formation material in the Marquette district to represent ferruginous vein-material and to have no stratigraphical significance; also, in the Vermilion district, it had mapped the iron-formation as Lower Huronian. When iron-formation was found to be unconformably below the base of the Lower Huronian of this district, it was referred to the Archean with the igneous complex previously so referred. The term Archean or Basement Complex had come to be generally regarded as one applying strictly to a basal igneous complex, and the term Algonkian was regarded as including all of the sedimentary rocks above such a complex and below the Cambrian. The reference, therefore, of sedimentary iron-formation to the Archean met with much opposition. However, the term Archean, by definition, has never been intended to apply strictly to igneous rocks. It has been held that the Archean complex is mainly igneous, although the possible sedimentary origin of some of it has been recognized, as in the case of the Kitchi schists and Palmer gneiss of the Marquette district. It has been meant to cover the members of the Basement Complex, not yet stratigraphically separable, beneath the well-recognized sedimentary series mapped Algonkian. The criteria for the separation of the Archean and Algonkian have been neither lithological alone nor structural alone, but a combination of both. A basal complex of greenstones, green schists, small shreds of iron-formation and slate—the latter so intricately infolded or interbedded as to make areal separation and determination of relations extremely difficult—is separated by a profound unconformity from a clearly sedimentary Huronian series, which is markedly less deformed and metamorphosed, allowing the application of ordinary stratigraphic methods. After sufficient definiteness has been reached in the major correlation it may be advisable to attempt further separations from the Basement Complex.

The simplest and clearest conception of the pre-Cambrian succession for the Lake Superior region may perhaps be obtained by thinking of it as primarily divided into six series—Keweenawan, Upper Huronian, Middle Huronian, Lower Huronian, Keewatin and Laurentian—all but the last two separated by unconformities of varying and disputed relative im-

portance, and with age-values not yet decided. These series may then be grouped under the two terms, Algonkian and Archean, thereby expressing our opinion that the unconformity at the base of the Huronian, in connection with difference in lithological characters above and below this horizon, should be singled out for special emphasis. If we believe, as Lawson does, that the essential break is at the base of the Upper Huronian series, his "Eparchean interval," then we should express our view, as he has done, by grouping all of the rocks beneath this unconformity under one major heading.

Since the manuscript of this paper was written, the joint committee of the Canadian and United States Geological Surveys, appointed to reach an agreement on disputed points of correlation and nomenclature, has completed its report, and recommends this nomenclature, without expressing opinion as to the desirability of a major grouping of the series under Archean and Algonkian. It is agreed further, in recognition of the difficulties of mapping broad granitic and gneissic areas in Canada, that the term Laurentian may sometimes be applied to areas of such rocks which locally may be known to be pre-Huronian, but which for the most part may be of unknown age.

The Iron-Ores.

Nature, Occurrence, Relations to Adjacent Rocks, Origin.

A general summary of the work of the U. S. Geological Survey on the iron-ores of the Lake Superior region is given by Van Hise.[11] The present summary covers much of the same ground, but includes, also, developments subsequent to the publication of his report.

The iron-ores of the Lake Superior region occur as concentrations in "iron-formations," ranging from a few hundred to 1,000 ft. or more in thickness. These formations, in their present form, represent the alterations of chemically deposited sediments, for the most part interbedded with normal clastic sediments, such as slate and quartzite.

Because of the definite stratigraphical position of the iron-ores, in contrast to many vein-deposits, the mapping and interpretation of the general geology of the region has been found to be of direct and practical value to the mining-industry, thus

[11] 21st *Annual Report of the U. S. Geological Survey.*

explaining the large expenditures by mining-interests on geological work.

In the Vermilion and Michipicoten districts the productive iron-formation is in the Keewatin division of the Archean. In the Mesabi and Gogebic districts the iron-formation is a part of the Upper Huronian series. In the Marquette district two productive iron-formations are present, one in the Middle Huronian and another in the Upper Huronian, the former being the more important. In the Crystal Falls district the iron-formation is in both Upper Huronian and Lower Huronian series, the former being the principal producer. In the Menominee district the formation is of Upper Huronian age.

The iron-formations of the different districts and ages are surprisingly similar in their general characters. Indeed, it was long assumed, erroneously, that because of their similarity they must be of the same age and origin. A single description will therefore suffice for them all.

The iron-formation consists mainly of chert or quartz, and ferric oxide, segregated in bands or shots, or mingled irregularly. Where in bands, with the quartz bands colored red and the rock highly crystalline, it is called jasper. Where less crystalline and either in bands or irregularly intermingled, the rock is known as ferruginous chert. In the Mesabi district the local name "taconite" is applied to the ferruginous chert. Other phases of the iron-formation subordinate in quantity are, (1) ordinary clay slates, showing every possible gradation through ferruginous slate into ferruginous chert; (2) paint-rocks, altered equivalents of the slates; (3) amphibole-magnetite schists; (4) cherty iron carbonate (siderite) and hydrous ferrous silicate (greenalite); (5) the iron-ores themselves.

It may be emphasized that almost the entire bulk of the iron-formation now consists of iron oxide and silica, with carbonates and alumina present in subordinate quantity. The varying combination of part or all of these constituents, mechanically, or chemically, or both, gives all of the rock-types above listed.

A series of cross-sections, Figs. 1, 2, 3 and 4, summarizes better than a description the structural relations of the ores to the adjacent rocks in the different districts and formations.

It has been shown that the ferruginous cherts, jaspers, amphibole-magnetite schists, and iron-ores of the iron-formation

result from the alteration either of the cherty iron carbonate or of ferrous silicate (greenalite), or, to a minute extent, from iron sulphide. The small amounts of iron carbonate or ferrous silicate now found in the formations represent mere remnants left

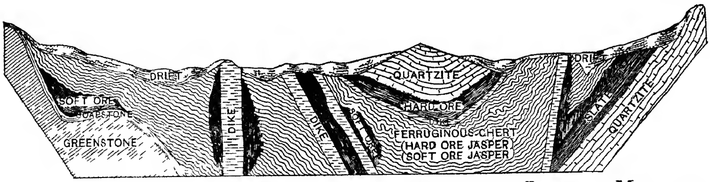

Fig. 1.—Generalized Vertical Section in Marquette District, Michigan, Showing Relation of Different Classes of Ore-Deposits to Associated Formations.

unaltered where so protected by other rocks as not to have been affected by altering agents. The steps of the alteration may be observed, and, in the end-products, the structures and textures

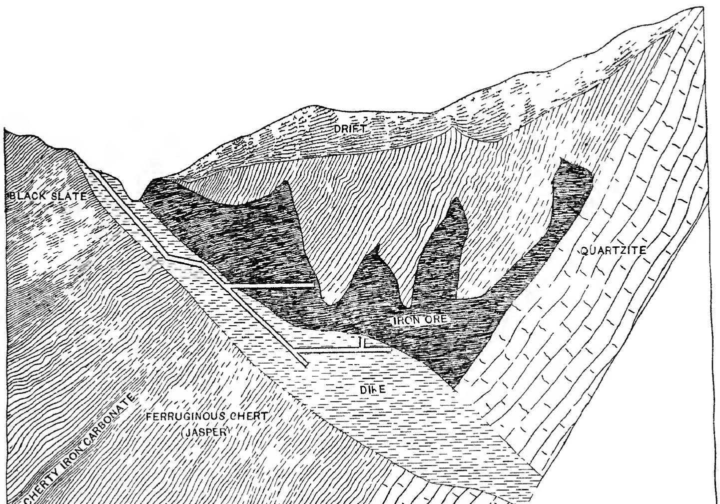

Fig. 2.—Generalized Vertical Section through Penokee-Gogebic Ore-Deposit and Adjacent Rocks; Colby Mine, Bessemer, Mich.

of the original rocks are often preserved to a remarkable degree. The chemistry of the change is summarized in Table II. Let it be emphasized that the ores and ferruginous cherts or jaspers and the amphibole-schists represent alterations from the

same original types. There is a prevailing notion that the original source of the ores is the jaspers or ferruginous cherts them-

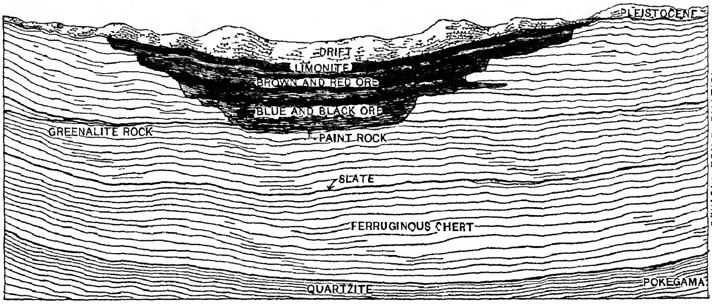

FIG 3.—GENERALIZED VERTICAL SECTION THROUGH MESABI ORE-DEPOSIT AND ADJACENT ROCKS.

selves, in their present form. While the leaching out of silica from such rocks does yield ore in many cases, it is believed that

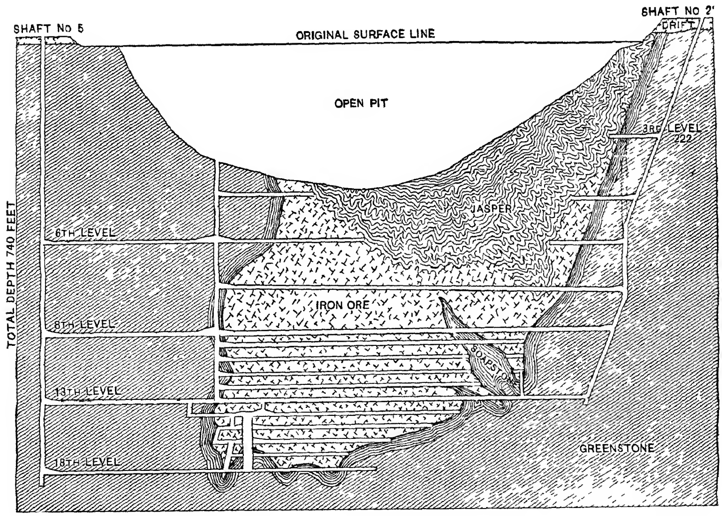

FIG. 4.—VERTICAL SECTION THROUGH ORE-DEPOSIT AND ADJACENT ROCKS OF VERMILION IRON RANGE; CHANDLER MINE, ELY, MINN

ores and jaspers, often of the largest deposits, develop side by side contemporaneously from the alteration of iron carbonates or iron silicates.

The agent of the alteration is water, coming more or less directly from the surface, carrying oxygen and carbon dioxide. The concentration of the ores has been found to occur where such waters have been converged. Various factors have determined this convergence—fracturing and brecciation of the iron-formation, existence of impervious layers in such attitudes as either to converge waters coming from above or to impound the waters and deflect their course between two layers. The presence of an impervious layer, forming a pitching-trough, is perhaps the most conspicuous structural feature determining the convergence of waters concentrating the ores. The impervious troughs consist, in the Mesabi district, of slate or paint-rock layers within the formation itself; in the Vermilion district, of greenstone with which the iron-formation is infolded or interbedded; in the Penokee-Gogebic district, of the intersection of diorite dikes with a foot-wall quartzite; in the Marquette district, of a greenstone intrusive into the iron-formation, or of a slate underlying the iron-formation; in the Menominee district, of dolomite underlying the iron-formation or of slate layers within the formation itself. In all these districts, except the Mesabi, the presence of this impervious basement seems to be clearly the controlling factor in the convergence of waters which have concentrated the ores.

In the Mesabi district, also, impervious troughs may be important, but they probably are subordinate to, or, at least, not more important than, other factors. The iron-formation and its associated rocks lie in beds on the south slope of the Giant's range, and dip off gently to the south at angles averaging from 8° to 10°. In addition to the general southward tilting of the beds, they are gently flexed into folds with axes transverse to the trend of the range. Waters falling on the south slope of the Giant's range, and flowing to the south, enter the eroded edges of the iron-formation and continue their way down along its layers, some of which are pervious and some of which are slaty and comparatively impervious to water. The flow thus tends to become concentrated along the axes of the synclines which pitch gently to the southward. Such synclines are not necessarily surface-troughs. They are evidenced by the attitude of the layers of the iron-formation, and may not be apparent in the unequally-eroded rock-surface or at the surface

of the irregular covering of glacial drift. The concentration of the flow along the synclines in the layers of the iron-formation seems so simple and evident that there is a temptation to generalize and say that the underground circulation has probably concentrated the ores along these broad synclines. When the district was first examined by the U. S. Geological Survey this simple explanation was applied. But further study shows that other factors modify the circulation of water and the localization of the ore, and that these secondary factors may be locally dominant.

The most important of these modifying factors is the fracturing of the iron-formation, which has furnished numerous trunk-channels for the circulation of underground-waters. The water has been confined to narrow, irregular and most devious trunk-channels formed by the fracturing of the iron-formation, and, while it has probably followed the fracture-openings along synclines to a greater extent than along anticlines, it has not filled the entire syncline formed by the folding of the iron-formation. The result is that the ores have developed along limited and irregular areas within the synclines. They may occupy a considerable part of the syncline, in which case the synclinal structure of the iron-formation may be observed in the layers of wall-rock adjacent to the ores. In other cases, they occupy so small a proportion of the syncline that the layers of the iron-formation in the adjacent wall-rock give no indication of synclinal dips. Not infrequently, several more or less independent deposits may have developed in the same general syncline, as, for instance, in the area adjacent to the town of Virginia. To put it briefly, the ores show such position, irregularity, extent, and relations to wall-rocks as to make applicable the expression sometimes heard in the district that the ores have developed through the "rotting" of the iron-formation along fractures, usually, but not always, in broad synclinal areas.

Other factors modifying the general underground-flow of water in the Mesabi iron-formation are the numerous impervious slaty layers within the iron-formation, and the Virginia slate capping the iron-formation of the south; all of which have considerable effect. So far as the water is free to flow southward through the iron-formation, the impervious layers serve

Table II.—*Origin and Development of the*

(Prepared for the St. Louis Exposition by C. R.

ORIGINAL ROCKS

The original rocks from which the iron ores have developed were deposited in sedimentary "iron formations" (in general in rather massive beds, but in part slaty), the iron of which was probably derived largely from the more ancient basic volcanic rocks of the Lake Superior region. The iron formations are underlain and overlain by sedimentary formations which are relatively impervious to water, such as quartzite and slate, also in part by Keweenawan gabbro. They are cut by intrusive rocks of various kinds, and characteristically folded and metamorphosed.

CHERTY IRON CARBONATE ($FeCO_3$, with $CaCO_3$, and SiO_2)

Locality			Age
Vermilion	District,	Minn	Archean
Michipicoten	"	Ontario	"
Marquette	"	Mich	Algonkian—Lower Huron
Penokee Gogebic	"	Wis and Mich.	" Upper "
Menominee	"	Mich	" " "
Crystal Falls	"	"	" " "

FERROUS SILICATE ROCK.

($FeSiO_3nH_2O$ with Mg and other impurities)

Mesabi District, Minn	Algonkian—Upper Huron

PYRITIC CARBONATE ROCK

(FeS_2 disseminated through carbonate iron formation of very subordinate importance)

Vermilion District, Minn	Archean
Michipicoten District, Ontario	"

CHEMICAL ALTERATIONS

CO_2 liberated

FeO uniting with SiO_2, and producing—

Grunerite (FeO SiO_2)

Fayalite ($2FeO$ SiO_2)

Fe, Mg, Ca, etc., uniting with SiO_2, and producing—

Cummingtonite	$(FeMg)SiO_3$
Chrysolite	$(MgFe)_2SiO_4$
Hornblende	chiefly $Ca(MgFe)_3Si_4O_{12}$
Actinolite	$(CaMgFe)SiO_3$

FeO partially oxidized, and producing—

Magnetite (FeO Fe_2O_3) (This occurs extensively where iron formation has been affected by Keweenawan gabbro intrusion)

Where FeS_2 (pyrite) is originally present in abundance, pyrite is found in resulting rocks

Partial oxidation of ferrous iron; formation of silicates, and removal of carbon dioxide.

Oxidation of ferrous iron, separation of silica and removal of carbon dioxide

I. CHERTY IRON CARBONATE

(1) $2FeCO_3 + SiO_2 + O + nH_2O = Fe_2O_3nH_2O + SiO_2 + 2CO_2$

(2) $2FeCO_3 + SiO_2 + O + nH_2O = Fe_2O_3 + SiO_2 + 2CO_2 + nH_2O$

(3) $5FeCO_3 + SiO_2 + 2O + nH_2O = Fe_2O_3 + Fe_3O_4 + SiO_2 + 5CO_2 + nH_2O$

II. FERROUS SILICATE ROCK.

$FeSiO_3nH_2O + CO_2 + nH_2O = FeCO_3 + H_4SiO_4 + nH_2O$

$2FeCO_3 + O + nH_2O = Fe_2O_3nH_2O + 2CO_2$

Also reactions analogous to (2) and (3) above

III PYRITIC CARBONATE ROCKS

$FeCO_3 + FeS_2 + SiO_2 + 6O + nH_2O = Fe_2O_3\ nH_2O + SiO_2 + 2SO_2 + CO_2$

Also reactions analogous to (2) and (3) above

Silica remaining

Silica removed

Iron-Ores of the Lake Superior Region.

Van Hise, C. K. Leith and W N. Smith.)

RESULTING PRODUCTS

AMPHIBOLITIC - MAGNETITIC ROCKS.
PYROXENIC - CHRYSOLITIC - MAGNETITIC ROCKS.

JASPILITE—"Hard Ore Jasper."

(Produced by dehydration and recrystallization of ferruginous cherts and ferruginous slates probably under conditions of deep burial, dynamic action, or igneous intrusion)

DETRITAL IRON ORES

(Formed by breaking up through wave action of pre-existing ores or ferruginous cherts and jaspers, in the latter case often involving concentration by assorting by leaching out of silica, and by subsequent enrichment)

Detrital ore (conglomerate ore) from base of Upper Huronian Sediment formed from pre-existing ferrug inous chert or jasper which has been subsequently desilicified and enriched

Detrital ore from Menominee district Mich, from base of Upper Huronian Sediment formed directly from pre-existing ores

Detrital ore from Menominee district, Mich., from base of Cambrian Produced by breaking up of pre existing ores

FERRUGINOUS CHERTS

(Produced by alteration of more massive bedded phases of iron formation)

I From Cherty Iron Carbonate ("Soft Ore Jasper")

II From Ferrous Silicate Rock ("Taconite")

FERRUGINOUS SLATES

(Produced by alteration of slaty phases of iron formation)

IRON ORES, HARD

Produced by further metamorphism of the soft ores and ferruginous cherts by processes which include dehydration, desilicification and enrichment by infiltration probably under conditions of deep burial dynamic action, or ig neous intrusion, or any combina tion of them

Blue non hydrated hematite

Red non hydrated hematite

Micaceous or specular non-hydrated hematite

Magnetite

MARTITE

Produced under weathering conditions by oxidation of magnetite to hematite

IRON ORES, SOFT

Soft Hydrated Hematite or Limonite

Hard Hydrated Hematite

only to limit the flow below. But the continuous south dip of the impervious strata carries the waters down to a point when the ground is saturated and the waters are ponded between impervious layers above and below. That ponding actually occurs is shown by the fact that drill-holes penetrating the slates and entering the iron-formation frequently meet water under pressure, indicating artesian conditions. When ponded, the water seeks the lowest point of escape, which is likely to be found near the north margin of the slate-layers. The movement of the water towards the lowest point of escape causes a considerable lateral movement in the circulation, and this lateral movement has probably, at least in part, controlled the shape of certain deposits on the range, which have their longer dimensions parallel to the strike of the layers of the iron-formation.

The ponding of the water and consequent overflow has still another effect. Where ponded the flow is governed by the point of lowest escape rather than by the shape of the impervious basement. When water is drawn off at the edge of a basin, the flow is greatest near the point of escape and diminishes in all directions away from that point. This statement is true, whether the bottom of the basin is flat or fluted; hence, in the Mesabi iron-formation, where the water is ponded, the flow is concentrated near the point of lowest escape regardless of whether this be over a syncline or anticline provided both are below water-level. The lowest point of escape is likely to be over synclines, but the surface erosion, both by glacial and meteoric agencies, has been such that this is not always the case. For this reason it is not certain that iron-ore deposits near the edge of the Virginia slate or near the edge of interstratified slate-layers may not have developed along arches as well as in synclines of the iron-formation.

The above facts are intimately related to the problem of finding ore under the solid black Virginia slate. The question is frequently asked, is there any reason why ore shall not be found under the black slate? The absence of ore under the slate has not been demonstrated by actual drilling; only a comparatively few holes have penetrated any considerable thickness of the Virginia slate and entered the iron-formation below. Yet such holes as have been put down have revealed

ore only near the slate-margin and frequently of low-grade. In several cases, the iron-formation beneath the slate has been shown to be of a green, unaltered variety, indicating that the alteration necessary for the development of ore-deposits has not gone far. If the development of the ore is dependent upon a vigorous circulation, and this vigorous circulation is lacking under the Virginia slate because of the ponding, we have here an adequate cause for the non-existence of ore-deposits under the black slate. Yet, further work may show that other factors have entered; and, considering the extent and value of the new iron-bearing territory, which would be thrown open were ore found under the Virginia slate, additional actual drilling seems to be advisable.

In the Gogebic district, while the impervious basement has been the controlling factor in the concentration of waters, and consequently of the ores, faulting through the dikes has afforded free passages for waters which have been taken advantage of, with the result that the ores follow such faulting-planes and are not uniformly confined to positions on the impervious troughs.

In Figs. 1, 2, 3 and 4, it will be noted that, for all of the districts except the Mesabi, the vertical element in the distribution of the ores is an important one. In the Mesabi district the horizontal element is the greatest one in most cases. Here, a single ore-body or a group of ore-deposits may give practically a continuous surface of iron-ore for several miles, with a depth ranging from a few feet to 400 ft. or more. In the other ranges a depth of ore of 1,000 ft. is common and 2,000 ft. has been exceptionally reached. It is not unlikely that in some places, particularly the Gogebic district, the ores will be found to greater depth, although the lower limit is well determined for the most part. Theoretically, the lower limit of the ore-bodies ought to be the lower limit of the active circulation of oxidizing waters from the surface. In the Mesabi district the proportion of the area of the ore-bodies appearing at the rock-surface, to that of the iron-formation as a whole, is about 8 per cent. for the productive part of the district, and 5 per cent. for the entire district. For the other districts of the Lake Superior region, the area of the iron-ore deposits is far less than this percentage of the area of the iron-formation as a whole. In bulk, the percentage of ores to the iron-formation is much smaller

throughout the Lake Superior country, for it will be remembered that the ores are essentially surface-alterations and are therefore well represented at the surface.

The alteration of the iron-formation, resulting in the concentration of the iron-ores or in the development of ferruginous cherts and jaspers and amphibole-schists, has taken place in different geological periods under various conditions, with a result that the ores of each of the districts, as well as of different parts of the same district, show considerable lithological variety. The same ingredients—iron oxide and silica—appear here mechanically combined as highly crystalline jasper, there in the hydration as a soft ferruginous chert, or both mechanically and chemically combined as an amphibole-magnetite schist. The iron-oxide may appear here as a brilliant specular hematite or magnetite, and there as a soft granular hematite or limonite. The ores of the Mesabi district are soft and granular and associated with ferruginous cherts. At the east end they become amphibolitic, magnetitic and non-productive. The ores of the Gogebic district are of a similar nature and become amphibolitic, magnetitic and non-productive at both the east and west ends of the district. The ores of the Vermilion district are hard, blue and red ores, at Ely, brecciated, associated with jaspers. The ores of the Marquette district comprise hard blue ores and brilliant specular ores associated with jaspers, called "hard-ore jaspers," soft ores associated with ferruginous cherts, or "soft-ore jaspers," and with underlying slates, and at the west end of the district, magnetite and specular hematite ores associated with jaspers and with amphibole-magnetite rocks.

Without going into the variable conditions in the several districts and the varying geological history of the different ores and rocks, it may be said that, so far as the alteration of the iron-formation has proceeded continuously under the influence of surface-waters without interruption by igneous activity or orogenic movements, the soft ores and ferruginous cherts have resulted. So far as these have been subsequently under deep-seated conditions of alteration, they have become dehydrated into hard red and blue specular ores and brilliant jaspers. This phase of the alteration did not require the agency of surface oxidizing-waters. So far as the alteration of the original iron-forma-

tion took place within the sphere of influence of great intrusive masses where the waters were heated and oxygen was not abundant, or under similar conditions developed by deep burial and orogenic movement, the iron oxide and silica of the formation combined with small amounts of other substances to form ferrous silicates, and the ferrous iron was oxidized to magnetite, making one of the variety of rocks usually described as amphibole-magnetite schists.

In the discussion of the development of the ores, we have begun with the original rocks of the iron-formation, namely, the iron carbonates and greenalite rocks, containing minute amounts of sulphide, which constituted the formation when it was first deposited. The origin of these rocks themselves is a subject of absorbing interest, but it is a subject in which direct evidence, such as we have been dealing with, is lacking; and a subject, furthermore, of less practical importance and less direct bearing upon the study of the ores themselves. Certain facts are well known. Both the iron carbonates and the greenalites (and their altered equivalents) constitute a conformable part of a continuous sedimentary succession, being interbedded, overlain and underlain by fragmental rocks, such as quartzite and slate. They are themselves bedded. It is impossible to escape the conclusion that they are water-deposited sediments. It is, further, clear that they are not water-deposited sediments of an ordinary nature. They are not fragmental; their nearest analogues are chemical sediments, such as limestones.

From here on in our explanation we must depend rather upon analogy with chemical sediments, such as limestone, and with iron compounds now being precipitated in bogs and lakes and elsewhere, than upon direct evidence in the formation itself. On this basis, the history of the development of these rocks, as outlined by Van Hise,[12] is as follows:

. . . "It is, however, my belief that the iron for the iron-bearing formations was largely derived from the more ancient basic volcanic rocks of the Lake Superior region. When the individual districts are taken up it will be seen that a greenstone, often ellipsoidal, in many places porous and amygdaloidal, in many places

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[12] The Iron-Ore Deposits of the Lake Superior Region, by C. R. Van Hise, 21*st Annual Report, U. S Geological Survey,* Pt III., pp 319, 320.

See also :

Monograph XLIII., U. S Geological Survey, by C. K. Leith

schistose, and rich in iron, is the most characteristic rock of the Archean, and that similar rocks occur abundantly in the Huronian. Where these igneous rocks were adjacent to the seas they would be leached by the underground water and the iron transported to the adjacent seas. It is probable that to some extent this leaching process also went on below the waters of the sea. The iron was probably transported to the water mainly as carbonate, but to some extent as sulphate. The carbonate would there be thrown down by oxidation and hydration as limonite, and the sulphate in part as basic ferric sulphate. Much of the sulphate was probably directly precipitated as sulphide by the organic material. The limonite would be mingled with the organic matter which was undoubtedly present, as shown by the associated carbonaceous and graphitic shales and slates. When deeply buried the organic matter would reduce the iron sesquioxide to iron protoxide. By the simultaneous decomposition of the organic matter carbon dioxide would be produced, which would unite with much of the protoxide of iron, producing iron carbonate. The sulphate of the basic ferrous sulphate would be reduced to the sulphide by the organic material, thus producing the pyritic carbonates. Where the iron was brought to the water mainly as sulphate the direct reduction of this salt by organic matter would form iron sulphide with little or no carbonate. Simultaneously with the production of these substances chert was formed, probably through the influence of organisms.[13]

"Some of this silica would unite with a part of the protoxide, producing ferrous silicate More or less mechanical sediment would also be laid down. Thus the original rocks—the cherty iron carbonates, the ferrous silicate rocks, and the pyritic cherts—would be produced

"It has chanced that at three different periods in the history of the Lake Superior region, these processes of the development of the original rocks of the iron-bearing formations have occurred extensively. While this might at first be thought remarkable, there is no good reason for thus regarding it. At some time during each of the Archean, Lower Huronian and Upper Huronian periods the quiescent conditions of chemical and organic sedimentation have occurred, and since the iron-bearing volcanic rocks were each time available for the work of underground waters and sea-waters, naturally iron carbonate and the other original rocks have been produced. In each period the source of the material and the process of its formation were essentially the same."

Time of Concentration.

The concentration of the ores of the Lake Superior region was far advanced before Cambrian time, as shown by the existence of ore and other iron-formation boulders, derived from the pre-Cambrian, in Cambrian conglomerates. For each of the districts the particular time of concentration has been more closely calculated, but this is a subject which would require a longer discussion than the scope of this paper warrants, and

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[13] The Penokee Iron-Bearing Series of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise: *Monograph, U. S. Geological Survey*, vol. xix., 1892, pp. 246–253.

Fossil Medusæ, by C. D. Walcott: *Monograph, U. S. Geological Survey*, vol. xxx., 1898, pp. 17–21.

the reader is referred to Van Hise's general paper already cited.

Topographic Relations of the Ores.

With very few exceptions, the ore-deposits of the Lake Superior region lie either on the slopes or at the foot of conspicuous ranges or hills. This has been explained by Van Hise as due to the concentration of ores through the circulation of ground-waters. Topographic elevations have given the waters sufficient head to search the ground on their slopes and perhaps at the base of the slopes. On the slopes the movement of the water is largely downward and more or less direct from the surface, thus carrying an abundance of altering agents, particularly oxygen and carbon dioxide; while in intervening low-lying areas, the waters escape with a lateral and upward movement after a longer underground journey, during which they have lost considerable proportions of the agents which alter the iron-formation to ores. Van Hise holds that, in the latter positions, the ores have not developed so abundantly as on the slopes. The present topography is, in many places, not the same in detail as the topography which existed at the time the ores were concentrated; and accordingly it is not safe, in discussing the relations of the ores to the topography, to consider too small topographic units. Believing that the present major topographic conditions represent, at least in part, the past conditions, Van Hise has discussed in some detail the relations of the Lake Superior ores to the particular topographic features of the different districts. In one or two cases, and especially in the Gogebic district, the topographic units selected for discussion may have been too small, and this has resulted in criticism of the entire theory. It is believed that his main conclusions as to the relations of the ores to the major topographic features have been confirmed, rather than disproved, by recent work.

Present Studies of the Origin of the Ores.

The ores of the Lake Superior region have been shown, in certain districts, to have been developed from the alteration of iron carbonate, in other districts from the alteration of iron silicate, and in others, from both. In the Marquette, Gogebic, Vermilion, and Crystal Falls districts, the original rock has

been described as iron carbonate. In the Mesabi district, the original rock has been described as consisting of ferrous silicate or "greenalite" granules principally, but with subordinate amounts of iron carbonate. In the Felch Mountain and Republic areas, the presence of granules similar to the Mesabi granules has been noted. In the Menominee district, both iron carbonate and silicate granules have been supposed to yield the ore.

The vast scale on which the alteration of ferrous silicate granules has occurred in the Mesabi district, together with the evidence of the somewhat wide-spread distribution of such granules in unknown but small quantity, has led to a re-examination of the ores and rock of the remaining districts, with the result that evidence of the prior existence of granules has been found also in both the Gogebic and Crystal Falls districts. So far as the re-examination has gone, however, it tends to confirm the essential correctness of the determination of iron carbonate as the original iron-formation rock for these districts.

In the new Animikie iron-range, on the northwest coast of Lake Superior, the eastern continuation of the Mesabi range, original and secondary iron carbonate and pseudomorphs after greenalite are found so well exposed and so closely associated that it is hoped that the study of this district now in progress will furnish decisive evidence of the real relations of these two substances.

In the new Baraboo iron-range of Wisconsin, which is of pre-Cambrian age and similar in many respects to the Lake Superior deposits, Weidman has attempted to show that the ores are original bog-deposits, which have become dehydrated. His conclusion does not necessarily affect the remaining Lake Superior ores, but the similarity in geology is so close that, until the contrary is proved, it is believed that the explanation applied to one region will apply substantially to others. Reasons are given on a subsequent page for believing that his explanation is not a true one.

Experimental work in the laboratories of the University of Wisconsin show the great ease of the alteration of the iron carbonates through the agency of water. In a few hours this substance becomes coated with hydrous iron oxide when treated with warm water containing only small amounts of oxygen de-

rived from contact with the air. Iron silicate has been found to be much more refractory, but still has yielded slightly to the action of ordinary water. Quantitative results are looked for at an early date. Analysis of mine-waters from the Lake Superior region as a whole, it is hoped, will yield results indicating the manner in which the ores and rocks of the iron-formation have been altered.

The form in which the phosphorus occurs is not definitely settled. Some of it is certainly in the form of apatite. But many ores, and especially Mesabi ores containing phosphorus, apparently do not contain apatite. The association of phosphorus with aluminum, both in ores and in other phases of the iron-formation, suggests the possibility that the phosphorus is chemically combined with aluminum. The solubility of the phosphorus compounds in the ores is still a mooted question. Incidents may be cited of the remarkable change of phosphorus-content in stock-piles and mines, because of the washing of surface-waters; and in drilling, allowances are frequently made for changes in phosporus-content in washing. Whether this is mechanical or chemical, its extent and its commercial importance are yet to be decided. It is hoped that investigations now in progress will settle these questions.

Iron-Ranges of Recent Discovery.

As a result of the vigorous exploration constantly going on in the Lake Superior region, new areas of iron-formation are discovered from time to time. Among those newly-discovered areas now receiving attention several may be particularly noted.

Baraboo Iron-Range.—The Baraboo quartzite-bluffs of south central Wisconsin constitute a pre-Cambrian outlier, surrounded by flat-lying Paleozoic rocks, well to the south of the main area of Lake Superior pre-Cambrian rocks. Within the last few years it has been discovered, largely through the explorations of Mr. W. G. La Rue, that, associated with the quartzite and beneath the Paleozoics are iron-formation, slate and dolomite. Iron-ore has been found in the iron-formation and the shipment of ore began in 1903. The district has been described in a bulletin of the Wisconsin Geological Survey by Dr. Samuel Weidman.[14]

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[14] The Baraboo Iron-Bearing District, by Samuel Weidman. *Bulletin No XIII.*, *Wisconsin Geological and Natural History Survey* (1904)

The Baraboo quartzite, having an estimated thickness of from 3,000 to 5,000 ft., forms an east-west synclinorium about 29 miles long and ranging in width from 2 miles on the east to 10 or 12 miles on the west, resting on a basement of Archean rock. The upturned north and south edges of the quartzite forms respectively the north and south ranges of the Baraboo Bluffs, standing from 700 to 800 ft. above the surrounding country and above the intervening valley. Minor rolls and faults bring the quartzite up at intervals in the valley. Resting conformably on the quartzite in the valley is the Seeley slate with an estimated thickness of from 500 to 800 ft., above this is the iron-bearing formation from 400 to 500 ft. thick, bearing the ore-deposits of the district, and above this is the Freedom formation, mainly dolomite, with a thickness estimated to be at least 800 feet. Recent drilling at the east end of the valley has shown the possible presence of another pre-Cambrian quartzite-formation unconformably overlying the dolomite, iron-formation and slate. Finally, flat-lying Paleozoic sediments unconformably overlie the pre-Cambrian rocks and partly fill the valley, and on these, in turn, rests glacial drift.

The main Baraboo pre-Cambrian series seems to be more nearly similar to the Middle Huronian of the Lake Superior region than to any other. The overlying quartzite series may represent the Upper Huronian.

The iron-ore is of low-grade (mainly below 55 per cent.) Bessemer hematite, with soft earthy, hard and black, and banded siliceous phases. A small amount of hydrated hematite or limonite is also present. The rocks immediately associated with the ore, and into which the ore grades, are dolomite, cherty ferruginous dolomite, ferruginous chert, ferruginous slate, and ferruginous dolomitic slate—in fact, all possible gradations and mixtures of the minerals dolomite, hematite, quartz, and such argillaceous minerals as kaolin and chlorite. In the ferruginous rocks associated with the iron-ore, the iron occurs, (1), as hematite; (2), as carbonate, isomorphous with the carbonates of calcium, magnesium and manganese; (3), as ferro-dolomite; (4), as manganic-ferro-dolomite; (5), as silicates combined with various proportions of alumina, lime, magnesia and manganese; (6), as chlorite and mica, and (7), very probably to a small extent as iron phosphate.

The iron-ore is stratified and is conformable with the associated stratified rocks, both below and above. The ore-bodies therefore have the dip and strike of the associated rocks, and are found dipping at various angles from nearly horizontal to nearly vertical.

At the Illinois mine, the first to be discovered and opened, 3 miles southwest of North Freedom, on the south limb of the syncline, the ore-deposit has a thickness of from 20 to 35 feet. The dip of the ore-body and adjacent formations is about 50° N. Between the ore and underlying Seeley slate are 100 ft. of alternating beds and thin seams of iron-ore with a considerable thickness of dolomite and ferruginous dolomite, ferruginous chert and ferruginous slate. Between the ore-deposit and the overlying dolomite are alternating strata of similar character grading up into the nearly pure dolomite. North of the Illinois mine a thickness of 600 ft. of dolomite is known to occur.

Underground exploration seems to show that the essential conditions and character of the rock existing at the Illinois mine prevail at other places in the district where ore has been found. Several such places are along the strike of the Illinois deposit on the south side of the valley, one on the north side of the valley, and one or more adjacent to the quartzite brought up by minor rolls or faulting in the central part of the valley. The ore, thus far found, lies along, or adjacent to, the eroded edges of the iron-formation. The few attempts to find ore within the deeply covered parts of the iron-formation, far removed from the eroded edges, have met with failure.

Dr. Weidman concludes that the Baraboo ores were originally deposited as bog-deposits and that their present character is due to subsequent dehydration. The evidence favoring this view is summarized by Dr. Weidman as follows:[15]

"1. The iron ore-deposits are bedded and, to all appearances, stratified like other sedimentary deposits.

"2. The stratified iron-ore deposits are not set off sharply from the surrounding associated stratified rocks, such as slate, chert and dolomite, but grade into them through all possible gradations. The iron-ore is not especially associated with any particular kind of the various rocks adjacent, and the stratification of these various kinds of rock is always conformable to that of the iron-ore. Since the slate, dolomite and chert are original sedimentary deposits, and since the iron-ore grades into them and is conformable to them, it is believed that the iron-ore has the same origin as these conformable interstratified deposits of related rock.

[15] *Op. cit.*, pp. 147, 148.

"3. That the physical conditions in the district at the time the iron-formation was deposited were favorable for the formation of such shallow-water deposits as iron-ore is indicated by the presence of sun-cracks in the rocks of the iron-formation immediately adjacent to the iron-ore and also by the presence of carbonaceous material, probably decayed vegetable matter in the iron-ore and associated ferruginous rocks. Furthermore, the rapid alternation in the various strata of the iron-formation indicates changing conditions of sedimentation,—a common characteristic of shallow-water deposits, and the composition of the iron-bearing formation itself, with its chert, carbonate rock and slate, is identical with the composition of shallow-water deposits being formed to-day

"4 That the iron-ore deposits originated long antecedent to the folding and fracturing of the iron-formation and the deposition of the mineral veins is shown by the fact that the strata of iron-ore are generally folded, crumpled and fractured, and that the mineral veins cut across the stratification and also across the folds of the iron-ore and associated rocks The folding of the ore-deposits appears to conform in all respects to the folding of the associated rocks, and the ore-deposits appear to have the position and distribution which they should have if formed before the general folding of the pre-Cambrian formations into their present position took place.

"5. The change in the ore subsequent to its original deposition as limonite, as shown by the microscopic and chemical study of the rocks, is believed to be mainly a change to hematite by dehydration of the limonite under deep-seated conditions of metamorphism This change is exactly parallel to the dehydration of the original clay-minerals of the gray Seeley slate-formation and of the clay-minerals in the slate-phases of the iron-formation, which now contain very little water of constitution, only 2 or 3 per cent, but which originally must have contained from 10 to 25 per cent This change of limonite by dehydration is also analogous to the probable dehydration of the original siliceous deposits now constituting the chert layers

"The geological data which led the writer to believe that the Baraboo iron-ore was very probably deposited as limonite under conditions similar to those under which bog- and lake-ore are formed to-day, and later merely partially dehydrated to form hematite, have just been briefly outlined The principal evidence believed to be directly opposed to the theory of the secondary development of the iron-ore as replacement- and alteration-deposits by work of the underground water is mainly furnished by the character of the work of the underground water at present, as indicated by its chemical composition, and by the work of the ground-water of the past, as indicated by the character and composition of the mineral veins in the ore and associated rocks

"From the study of the composition of the ground-water now circulating through the iron-bearing rock and associated formations in the district, and its comparison with that of ground-water outside the district and with river-waters and with chalybeate mineral waters, it has been concluded that very probably the present work of the ground-water in the iron-formation is not that of depositing iron-ore. It is quite generally accepted that mineral veins are deposited from underground water circulating through fractures in rocks; and the fact that the mineral veins in the iron-ore and associated rocks are largely quartz and not iron-ore is interpreted as evidence that the work of the ground-water of the past was very probably not that of depositing iron-ore. If the work of circulating ground-water of the past could have or did develop the iron-ore deposits, why should not the work be now in progress, since ground-water is now circulating through the ore-deposits and associated rocks as it has in the past; and if the iron-ore could have been or was developed by the work or agency of ground-water, why should

not the mineral veins that ramify through the ore-deposits and associated iron-bearing rocks be composed largely of iron-ore instead of quartz?"

As the Baraboo district is related geographically and stratigraphically with Lake Superior ore-bearing districts, Weidman's conclusion that the ores are original deposits immediately suggests that the same origin may hold for the ores elsewhere in the Lake Superior region, or, vice versa; and that explanations of the secondary origin of the Lake Superior ores may really apply in the Baraboo district. It is believed that Weidman has not proved the Baraboo ores to be an original deposit, for the following reasons:

His arguments 1, 2 and 3, without change, may be used equally well in support of a theory of secondary concentration from an originally deposited chemical sediment—iron carbonate or iron silicate—described as laid down in shallow waters.

No evidence is presented in support of argument 4. The secondary alteration of previously folded and contorted iron-formations to iron-ore, with the retention of all the folded and contorted structures, is the common feature for the Lake Superior country. Accompanying and following this change, there has been some additional folding, followed in some cases by an introduction of normal mineral veins, but usually it has been a minor phenomenon. The fact of the folding and contortion of iron-formation layers could not be accepted elsewhere in the Lake Superior country as evidence of the subsequent occurrence of the major folding.

The argument that the presence of quartz-veins shows that quartz only, and not iron-ore, has been introduced or concentrated subsequent to the deformation, it is believed, will not stand analysis. In the Lake Superior region, abundant evidence may be presented to show that quartz-veins have developed both before and after the concentration of the iron-ore, and I know of no criteria that will enable one to say that the presence of quartz, rather than iron-ore, in particular fractures or veins, proves or disproves the secondary origin of the ore. In the Vermilion district, minute veins of ore may be seen crossing both quartz-veins and an earlier concentration of the ore, and in turn are crossed by later quartz-veins.

The dehydration of limonite (5) has probably occurred, but it would make little difference whether the limonite were an original deposit or were itself a secondary alteration.

The argument that the composition of the waters seems to show that ore-concentration is not at present occurring is beside the mark when we remember that for the Lake Superior region as a whole, and hence for the Baraboo district itself until the contrary is proven, the concentration of the ores was largely finished before Cambrian time. The conditions at that time doubtless differed widely from present conditions, but even admitting that they are similar, the fact that waters from the iron-formation, which have been analyzed, contain no ingredients different from the surface-waters of the region, does not show that they may not still be doing work. Van Hise has emphasized the fact that the ordinary surface-waters are the ones that do the work, and that the development of iron oxides from iron carbonates and iron silicates is the normal work of percolating-waters for the belt of weathering in general. The presence of silica in the Baraboo waters shows that silica is being carried away from this general zone or region, and there is every reason to believe that it may be carried as well from the ore as from the overlying sandstone. Certainly it could not be assumed that the silica contained in the water, notwithstanding the fact that it is no more abundant in mine-waters than elsewhere, might not be coming from the ores themselves, thus enriching them. It is believed, also, that the process of alteration has gone so far in the mines from which the waters were secured, that the waters, now circulating there, are, for the most part, in contact with oxidized products—the end-products of alteration under such conditions—and that they could scarcely be expected to contain any considerable amounts of ferrous compounds. It is not at all certain that waters, working through less-altered parts of the formation, either in the past or elsewhere in this district, might not show a different composition.

Finally, Weidman's theory would require that, after straightening out the secondary folds and contortions, the iron-ore should lie in a continuous even bed or layer, having only such irregularities as would result from uneven deposition in shallow waters. If, in the Lake Superior region as a whole, the iron-formation layers should be straightened out, the resulting bed or layer would have strange shapes indeed, and would here and there end abruptly along the strike or dip, against other phases of the iron-formation or even against a dike or boss of greenstone. (See Fig. 1.) Indeed, Weidman's theory is

squarely opposed to nearly all conceptions of the structural relations of the ores to the adjacent rocks, worked out independently for each of the Lake Superior districts, where exploitation has gone far enough to allow of satisfactory study. It is believed that these structural facts, worked out for the region as a whole, will apply in the Baraboo district itself, so far as the facts are known in the present state of exploration.

The ores thus far found have been along the eroded edges of the iron-formation. Attempts to locate the ore in the center of the great Baraboo valley beneath the dolomite have met with failure. Straightening out the folds in the iron-ore bodies, and reproducing the original attitude and distribution, the iron-ore deposits would appear, so far as is now known, as a series of lenses, limited by dolomite or feathering-out beneath it, down the dip, in the direction of what is now the center of the valley. On Weidman's theory, the ore might be found anywhere beneath the dolomite, and its truncation by an erosion-surface would be purely a matter of accident. It must be admitted that drilling has not gone sufficiently far to prove that the iron-ore lenses uniformly reach the pre-Cambrian erosion-surface at some point; but sufficient drilling has been done to lead certain mining engineers of the district and myself to conclude that the evidence is strongly in favor of this view and that the normal Lake Superior conditions here prevail.

While it is believed, for the above reasons, that Weidman's conclusion as to the origin of the Baraboo ores is not supported by the evidence he has presented, the fact that the ore grades into, and is overlain by, dolomite—a unique occurrence for the Lake Superior region—would make it easy to accept an explanation of the origin of the Baraboo ores different from that applied to the remaining Lake Superior ores, if sufficient evidence be presented; and such acceptance would not necessarily imply a revision of views of the secondary origin of the remaining Lake Superior ores.

Cuyuna Iron-Range.—Iron-formation, containing ore of possible commercial grade, has been recently found in Crow Wing county of north central Minnesota, where surface-indications are slight. The discoverer was Mr. Cuyler Adams, of Duluth. For some years magnetic variations had been known in this general area, and the existence of a quartzite-ledge near Dam lake, south of Kimberly, in Aitken county, 15 miles to the east,

had been taken to represent the southern margin of the Mesabi syncline by the Minnesota Survey, Mr. Merriam, Geologist of the U. S. Steel Corporation, and others. I published a sketch showing the hypothetic structure of this part of Minnesota on the basis of this and other exposures in 1903.[16] Combining a careful magnetic survey with a conception of the general structure, somewhat as above noted, Mr. Adams began drilling in the area adjacent to Deerwood, which happens to be a drainage-divide. This led, in 1903, to the discovery of a magnetite-ore of low-grade, associated with amphibole-magnetite rocks. Further exploration, in 1904, has shown the presence also of hematite-bodies in adjacent areas.

The magnetic lines and drilling indicate the presence of two iron-formation belts, one 15 miles long running from a point a little east of Deerwood in a southwest direction, and another 2 miles long, parallel to the first and 6 miles to the northwest of it. I will shortly publish, elsewhere, a description of this area so far as the facts are known from present drilling. It may be said here, that the iron-formation associated with the ore is, for the most part, of the metamorphosed amphibole-magnetite variety, similar to the metamorphosed portions of the iron-formations elsewhere in the Lake Superior region. So far as present information goes, the iron-formation of the Cuyuna range might be, from its lithology, correlated with the metamorphosed Vermilion, metamorphosed Mesabi, or metamorphosed Marquette iron-formation; that is, it might be of Archean, Middle Huronian or Upper Huronian age.

Animikie Iron-Range.—Extending from Gunflint lake along the international boundary northeast to the east end of Thunder bay, on Lake Superior, is the Animikie (Upper Huronian) series, which may be called the eastward continuation of the Mesabi iron-bearing series. The Animikie series is similar to the Mesabi series in that it consists principally of a great slate-formation underlain by a comparatively thin iron-formation. It differs from the Mesabi series, as typically developed in the productive part of the Mesabi range, in lacking a basal quartzite, in containing intrusive sills, and in being in some places more metamorphosed. The presence of iron-formation in the Animikie series was known long before the dis-

[16] *Monograph XLIII., U. S. Geological Survey*, Fig 8, p. 203

covery of the Mesabi range; indeed, the series carrying the ores in the Mesabi range was first called the Animikie series, because of its similiarity to the Animikie series on Thunder bay or Animikie bay on Lake Superior. Exploration for ore of commercial grade and quantity, in the part of the Animikie series extending from Gunflint lake to the east end of Thunder bay, has long been unsuccessful. Renewed activity in the Loon Lake district, about 25 miles east of Port Arthur, has recently again attracted attention to the Animikie series. Here, hematite bands from a few inches to 18 or 20 ft. in thickness and averaging in composition, for the most part, below 50 per cent. of metallic iron, have been found extending over considerable areas. There seems to be more concentration here than anywhere else in the eastern portion of the Animikie series. It may be that, with hand-sorting, a low-grade of hematite could be shipped from here under the unusually favorable conditions of proximity to Lake Superior water and demand for Canadian ore for Canadian furnaces; but this is yet to be proved.

The geological conditions in this region have warranted close study. Mr. W. N. Smith,[17] of the University of Wisconsin, is now preparing a special report on this region. In the course of his work he has discovered the previously unknown existence of a Lower Huronian sediment in this vicinity, and has found the Keweenawan series, with a great conglomerate at its base, to rest, in turn, on the eroded edges of each of the different phases of the Animikie series and of the Lower Huronian adjacent; proving conclusively the strong unconformity between the Keweenawan and underlying series. Nowhere in the Lake Superior region can this unconformity be seen to such good advantage as here. He has worked out, also, the presence of definite horizons in the iron-formation, each of them characterized by iron carbonate or of pseudomorphs of greenalite, or both, from which the ores have developed; and has the data at hand for determining finally the true relations of these substances. Also, he has determined the existence of considerable faulting, which is partly responsible for the bending and contortion of the iron-formation layers in this area, and proba-

[17] Animikie, Loon Lake, Iron-Bearing Deposits, *Mining World*, February 18, 1905, pp 206–208.

bly also for the unusual concentration of ore, which is found along its brecciated edges.

Other Iron-Ranges in Ontario.—The presence of iron-formation is known in a very considerable number of localities in Ontario outside of the Animikie belt. Lists and descriptions may be found in recent reports of the Ontario Bureau of Mines. The commercial value of these new finds has not yet been shown. Geologically, those occurring near Lake Superior belong, almost without exception, to the Keewatin division of the Archean or Basement Complex; that is, they are similar in their occurrence and relations to the Soudan formation of the Vermilion district of Minnesota. Principles developed in the study of that district have been found to be of advantage in exploration for iron-formation in Ontario. The only producing-mine in the Ontario portion of the Lake Superior region is the Helen mine at Michipicoten, but magnetite-ores are known in sufficient quantity to be mined in two localities—in the Moose Mountain range north of Sudbury and in the Atikokan district west of Port Arthur—and they may occur elsewhere.

Exploration of Quartzite Areas.

The discovery of ores in covered areas adjacent to the Baraboo quartzite, together with the conspicuous association of quartzite with iron-formation in the Lake Superior district, has led to much study and some underground exploration of areas adjacent to other known pre-Cambrian quartzites of the Lake Superior region. Quartzite is the most resistant of the Huronian series, and it would be expected that it would stand up in conspicuous exposures; while associated softer formations, such as slate- and iron-formation, might be eroded and covered in the low-lying adjacent areas. The exposure of quartzite near Dam lake, referred to in the discussion of the Cuyuna range, has long been supposed to indicate the possible southern edge of the Mesabi series; and drilling has been done on this hypothesis. In the Waterloo area of southern Wisconsin, about 25 miles to the east of the Baraboo district, quartzite-exposures are known in such attitudes as to indicate the possibility of their constituting another east-west synclinorium similar to the Baraboo synclinorium, and nearly along the strike of its axis. Presumably, exploration will in time be conducted there to

show whether or not, iron-formation is present with the quartzite. Near the Neecedah quartzite, drilling has already been done, without finding ore. The Chippewa and Barron county quartzites of northwestern Wisconsin have no associated iron-formation rocks exposed, but exploration will doubtless be conducted in low-lying adjacent areas to determine definitely their presence or absence. The quartzite near Lakewood in northeastern Wisconsin may perhaps represent the southern extension of the Menominee range. In fact, before the Lake Superior region can be said to be thoroughly explored, practically every isolated known quartzite-area must be investigated.

The fact that quartzite underlies the ore in the Mesabi and Gogebic districts, as well as in the newly-discovered Baraboo district, would naturally lead one to explore first, the low-lying ground in the direction of the dip of the quartzite, that is, the horizons stratigraphically above the quartzite. But attention is called to the fact that there are, in the Lake Superior region, quartzites of three different ages, the Lower Huronian, Middle Huronian, and Upper Huronian; that correlation of any particular quartzite-area with quartzites of known age is practically impossible on the basis of lithological similarity; and that there are for any quartzite-area several possibilities as to the occurrence and distribution of any iron-formation rocks which might be found adjacent.

Work Yet to be Done.

With the appearance of the final general monograph on Lake Superior geology, now in preparation, the plan of the United States Geological Survey, inaugurated 20 years ago, will have been carried out. But it must be apparent from a perusal of the foregoing pages, that the study of the geology of the Lake Superior region is still far from completion. The work thus far accomplished has outlined the major problems and settled many of the important ones, but doubtless, 20 years hence, geologists will still be wrestling with problems of importance. A consideration of the results obtained and the problems still open, keeping in mind the number of men engaged and the funds available for the work to date, enables one to appreciate the extreme complexity of Lake Superior geology and the painfully slow progress which is possible.

The Occurrence of Pebbles, Concretions and Conglomerate in Metalliferous Veins.

BY EDWARD HALSE, PUERTO BERRIO, COLOMBIA, SOUTH AMERICA.

(Lake Superior Meeting, September, 1904.)*

THE occasional occurrence in metalliferous veins of rounded fragments of rock, matrix or ore, lying loose, embedded in clay, or enclosed in some kind of cement, may be attributed to four causes:—

I. They have been washed in from the surface, or from an upper portion of the vein.

II. They are of concretionary origin.

III. They have been produced by movements in the country-rock or in the walls of the vein.

IV. They have been formed *in situ*, by the upward, downward or lateral flow of water in the vein itself.

In this paper the word "conglomerate" is confined to a rock composed of rounded fragments or pebbles cemented together, as distinguished from a "breccia," in which the rock-fragments are angular.

I. BOULDERS AND PEBBLES WHICH HAVE BEEN WASHED IN FROM THE SURFACE, OR FROM AN UPPER PORTION OF THE VEIN.

In this type it is presupposed that the vein at one time communicated by a fissure or open space with the surface, or with the upper portion from whence the fragments have been washed.

One well-authenticated occurrence was described long ago by Fournet. Owing, no doubt, to later dislocations in the lode, pebbles from an old alluvium and sands containing titaniferous iron, as well as fragments of wood, were found in a vein at Huelgoet, in France.

"Toutes les parties tendres du filon de Pranal ou ces phénomènes sont les plus prononcés ont été excavés jusqu'a d'assez grandes profondeurs par l'impétuosité des torrents, qui ont deposé la matière alluviale."[1]

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* Revised proof not received in time for publication in vol. xxxv. of the *Transactions* (see *Trans.*, xxxv., p. xlv).

[1] *Études sur les Dépôts Métallifères*, Paris, p. 162, 1834.

Other pebbles found at Huelgoët will be referred to when discussing Group III.

According to T. A. Rickard,[2] at Rowe, near Pontgibaud, in France,

"At a depth of 164 ft from the surface, a fault-fissure encloses a mass of clayey material containing boulders of a black, soft and porous rock, which can be identified as pieces of scoriaceous lava. No such rock occurred elsewhere underground, and the boulders must have been portions of the quarternary alluvium which covered the outcrop of the lode, and fell into it at the time of its intersection by an open fissure, which long post-dated the formation of the ore-vein itself. . . ."

Sir Henry T. De La Beche[3] remarks that,

"The slate and quartz-pebbles of Relistran mine (Cornwall, England), cemented by oxide of tin and bisulphuret of copper, have long been known. Mr Carne states that they occurred at the depth of 600 ft below the surface in the tin lode, the mass being about 12 ft in length, and as many in width and thickness, scattered pebbles being found in the vein far beyond the boundaries. It has been doubted that these are true pebbles; . . those specimens, however, which the Survey procured from various sources, some from Mr Carne himself, can leave little doubt on the subject, more especially as rounded pebbles of quartz are mixed up with those of the slates, which are also most clearly seen to be such In the Wheal Badger lode, near Relistian, pebbles of granite are mixed with others of slate and quartz; and Mr Carne mentions pebbles having been found in the tin-lode of Ding Dong mine, near Penzance, and in the upper lode of Wheal Alfred, near Gwinear"

Nevertheless, as will be seen later, many of these pebbles are undoubtedly of concretionary origin.

D'Aubuisson[4] noticed the occurrence of pebbles of gneiss in the lode at Joachimstahl, at a depth of 1,152 feet.

The following appears to be an instance of boulders, etc., having been washed in from an upper portion of a lode:[5]

". . . Captain William Penrose, who then worked at the back of the 135-fathom level, at Frances shaft (Consols mines, Gwennap, Cornwall, England, in 1830 and 1832), states to Mr. R. Fox, that at that place for more than 25 fathoms in length and 15 fathoms in height, the lode was from 8 to 12 ft wide, and full of fragments and copper-ore, some of the fragments of slate weighing several tons, and occurring, as to the position of their laminæ, in all directions. He also states that many of these masses and smaller stones had the appearance of having been washed by a flow of water Above this mixed mass, and in the level above, a great cavity or vug was found many fathoms in length and height, from whence it was conjectured the fragments beneath had fallen. . . ."

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[2] Vein-Walls, *Trans.*, xxvi, 231, 232 (1896).

[3] *Report on the Geology of Cornwall, Devon and West Somerset*, by Sir Henry T. De La Beche, London, pp. 322–3 (1839)

[4] *Traité de Géognosie*, t. iii., p. 411.

[5] Sir Henry T. De La Beche, *op cit*, p 324

About twenty years ago I saw somewhat rounded pieces of hard clay-slate, spotted here and there with galena and sphalerite, which had apparently been washed into a vug occurring in a vein in Cardiganshire, South Wales, at a depth of 300 ft. from the surface, and below the water-level. The fragments had every appearance of being older vein-matter, and were mixed indiscriminately with other fragments of clay-slate, and with sphalerite, galena, cerussite and pyrite, these minerals forming a kind of loose cement around the fragments of rock.[6]

With regard to the Relistian pebbles, or "globular concretions," as they were termed by W. J. Henwood, Sir C. Le Neve Foster, "who saw similar masses in the lode at New Rosewarne, on a continuation of the Relistian lode, considers them—though with some hesitation—to be true pebbles, fallen in from above."[7]

II. Rounded Masses of Concretionary Origin.

Concentric structure has been produced in various ways, of which three chief ones may be mentioned:

1. *Solidification from Fusion.*—Crystalline concretions are occasionally found in eruptive rocks consisting of concentric layers of different minerals, or it may be of a single mineral. As examples of this class may be quoted, the "orbicular diorite" of Corsica, and the "pudding-granite" of Craftsbury, Vermont; the latter, according to James D. Dana,[8] contains large black ovoidal concretions consisting chiefly of black mica. At Bahia, Brazil, Charles Darwin[9] noted the occurrence of concretions of granular feldspar, and others of garnet, with mica in gneiss.

2. *Decomposition along Fracture-Planes.*—At the surface a much-fissured or jointed rock may, by oxidation, soon be reduced to a pile of boulders, frequently showing concentric structure, and in veins, above the water-level, or in the vadose circulation, the same kind of action may go on, although at a much slower rate.

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6 *Report of the Royal Polytechnic Society of Cornwall* for 1884

7 As cited by J. H. Collins, "On the Origin and Development of Ore-Deposits in the West of England." *Journal of the Royal Institute of Cornwall*, vol. xi., Part I., p. 179 (1894).

8 *Manual of Geology*, 4th ed., p. 97.

9 *Geological Observations on the Volcanic Islands and parts of South America visited during the Voyage of H. M. S. "Beagle,"* by Charles Darwin (New York, 1891), 422.

3. *Growth.*—To this cause is due by far the most frequent kind of concretion found in veins. The growth is from the interior outward, or peripheral—that from the exterior inward, or centripetal, will not be considered here, as probably no example of it occurs in ore-bearing veins.

Cockade-, ring-, sphere- or spherulitic ores (*Cocardenerze*, *Ringerze* of the Germans) are of the former type. Thus in one mine at Clausthal, a fragment of clay-slate or calcite forms the kernel and is surrounded by layers of quartz, galena and blende.

Another instance is given by Kemp:[10]

> . . . "Thus the Bassick, at Rosita, Colorado, referred to above, consists of rounded cores of andesite, inclosed in five concentric layers of metallic sulphides. The Bull Domingo mine, in the same region, exhibits shells of galena and quartz mantling nodules of gneiss. Such cores strongly resemble water-worn boulders"

At Huelgoet, pebbles are formed of a central nucleus of slaty country-rock surrounded by an envelope of slightly chalcedonic quartz.[11] They occur in the lead-veins cemented together by sphalerite, pyrite, quartz and galena, giving the lode the appearance of a conglomerate. Fournet speaks of the pebbles (*galets*) occurring in breccias on the hanging-wall or foot-wall, especially the latter. The fragments of quartz have sometimes preserved their angles "mais ils sont émousées (blunted) comme les galets qu'on trouve sur la bord des rivières."[12]

The concretions are not always in concentric layers, they may be formed of one mineral having a radial crystalline texture (German *Spharentextur*), surrounding a central core. In the district of Taviches, Oaxaca, Mexico, I have seen spheroidal hollows or vesicles in hornblende-andesite filled with radiated quartz, the center of which is sometimes formed of a small piece of dark ruby silver or pyrargyrite.[13]

The quartz in this instance has no doubt crystallized out from solution; but sometimes, radiated structure has resulted from cooling after fusion, or by alternate heating and cooling, as has been proved experimentally.

The pebbles of Relistian have already been mentioned. The

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[10] Kemp, J. F., *Ore-Deposits of the United States and Canada*, 1st ed., pp. 36, 37.

[11] Phillips' *Ore-Deposits*, H. Louis' ed., p. 88, Fig. 38 (1896).

[12] *Études*, p. 229.

[13] *Transactions of the* (Brit) *Institution of Mining Engineers*, 1900, vol. xviii., pp 380–381, and *Trans.*, xxxii., 294, Fig. 16 (1902).

majority of them are undoubtedly true concretions. W. J. Henwood writes:[14]

"A cursory inspection reveals but little, a narrower scrutiny, and the breaking of the rock, however, will in many cases discover that it consists of a large number of spheroidal masses cemented together by a matrix, sometimes quartzose, but oftener slaty. These round stones are sometimes massive, and at others schistose slate, and in one case in Relistian I have seen a piece of elvan so enclosed, whilst at Trevaskus globular lumps of copper pyrites are often surrounded by quartz, and in the Badger lode, in Herland, round masses of granite, slates and elvan are indiscriminately mixed, and cemented together by a basis which is sometimes of feldspar and quartz with a little mica, and at others of quartzose slate, iron, and copper pyrites . . . In Relistian round masses of slate are enclosed in quartzose slate, chlorite, tin-ore and in iron as well as in copper pyrites, and these stones are also frequently encrusted with crystals of tin-ore. . . . At Duffield round pieces both of slate and elvan occur; and at Trevaskus balls of slate and of quartz often prevail . . . In all these lodes this structure shades off into the containing-rock, and not uncommonly one end of a piece of slate exhibits this spheroidal form, whilst the other passes off into the contiguous homogeneous slate, from which it is nowise distinguishable. In other places the slates, as well as the intermediate rocks and the lodes, affect a concretionary structure like that which I have remarked in the elvan-courses at Relistian, Redruth and Pulla, and the unconnected globular masses of granite in the slate at Herland, and of elvan at Cairn Brea."

Henwood termed this "conglomerated" or "spheroidal" structure, and appears to include some crystalline concretions in the definition; in his later work on ore-deposits,[15] he describes and gives an undoubted example of ring-ore occurring at Wheal Trelawny. A kernel of galena is enveloped by four layers of quartz, the fourth containing fragments of the third, and coated all over with galena.

In the district of Sultepec, Mexico, wide cavities are found here and there in the silver-bearing veins, filled with nodules of pyrite, sphalerite and galena mixed with quartz, which are coated with calcite or siderite.[16]

Posepny's phrase, "crusted rock-kernels," of which he gives several examples in his well-known work,[17] seems hardly applicable to the above. The older term "ring-ore" or "sphere-ore" is to be preferred.

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[14] Metalliferous Deposits of Cornwall and Devon, *Transactions of the Royal Geological Society of Cornwall*, vol. v., pp. 39–40, 183–4 (1843).

[15] Observations on Metalliferous Deposits, *Trans. Roy. Geol. Soc. Cornwall*, vol. viii., p. 703, Fig. 32 (1871).

[16] Bartolome F. Villanueva, *Distrito de Real de Sultepec*, Mexico, 1888, p. 12. See also *Transactions of the* (Brit.) *Institution of Mining Engineers* (1904).

[17] Franz Posepny, *Genesis of Ore-Deposits*, Figs. 10 to 35

III. Conglomerates and Breccias which have Resulted from Movements in Rock-Masses or in the Walls of Veins.

The conglomerate-breccias of the Vermilion Range, Minnesota, have resulted from movement in rock-masses. Messrs. Smith and Findlay state:[18]

"The first step seems to have been the formation of intersecting sets of planes of fracture, dividing the original massive rocks into roughly rhomboid blocks Its further development depended on continual movement between these blocks under pressure, which resulted in enlarging the shearing-zones at the surfaces of contact, and rounding the angles The slate and jasper inclusions originally plucked off from the rocks which the porphyries and greenstones invaded, shared, of course, the subsequent history of their captors. The fact that the jasper inclusions are frequently rounded, while those of slate are not, is explained by the difference in the elasticity of the two rocks. . . . The boundaries of the inclusions have generally been the surfaces along which the rupture has taken place. . . ."

The above-mentioned effect is most developed on lines where the folding was most severe, that is, on the axis of the anticline.

In metalliferous veins, rounded fragments have sometimes been produced by movements in the walls. One instance of a rounded fragment, showing scratches or lines of friction, illustrated by Dr. Richard Beck,[19] occurs in the Daniel lode of the Himmelsfürst mine. As a rule, the fragments are angular, and have subsequently been cemented together, forming what are sometimes termed friction-breccias. These instances are well known.

IV. Conglomerate Formed *in Situ* by the Flow of Water in the Vein Itself.

S. F. Emmons[20] is of opinion that the rounding of fragments in veins

. . . "is readily accounted for as the action of percolating waters; it being a well-recognized fact that the decomposing action of moisture in any form acts more rapidly on the corners or angles of a rock-mass than on its flat surface, and the sharper the corner the more rapidly is it eaten away"

During the last five years I have found specimens of what appears to be a true or water-worn conglomerate, both above

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[18] H. L. Smith and J. Ralph Finlay, *Trans*, xxv., 632, 633 (1895–6); for similar structure in aphanitic greenstones of the Marquette district, see G. H. Williams, *Bulletin* No 62, *U. S. Geological Survey*, pp 163 to 173

[19] *Lehre von den Erzlagerstatten*, vol. i, Fig. 90 (1901) Fig. 91 shows a *Kugelgang* on the hanging-wall, some of the fragments of which are more or less rounded.

[20] Structural Relations of Ore-Deposits, *Trans.*, xvi, 804 (1887–8).

and below water-level, in a gold-bearing vein in the Remedios district, Antioquia, Colombia, South America.

The principal characteristics of the vein—known as the Sucre lode—are as follows:—The strike is E—W., afterwards changing to NW—SE.; the dip is flat, being N. 20° to 30° only.

The country is hornblende-granite,[21] which, in places, is distinctly bedded, the beds or joints coursing about N—S. and dipping from E. 40° to 73°. The unaltered rock contains many dark patches or segregations of hornblende crystals embedded in large plates of feldspar and some quartz; but the latter mineral is far less abundant than in the surrounding granite. Frequently, one wall of the vein, specially where the ore-shoots occur, consists of hornblende-diorite-porphyrite, as determined by Dr. John S. Flett. The ore-shoots proper are short in length, varying from 100 to 300 ft., and are separated from each other by a considerable extent of practically barren quartz-filling. Their continuity in depth, so far as they have hitherto been exploited, is usually unbroken, except where cut off, perhaps temporarily, by faults striking with the vein, and dipping in a contrary direction thereto. The deepest mine in the district is that known as "El Silencio," owned by the Frontino and Bolivia (South American) Gold-Mining Company, Ltd., of London. The vertical depth is about 366 ft. on a N—S. lode. The ore in the bottom, or No. 10 level, is rich. The underlay shaft is 710 ft. deep. The average dip of the lode is E. 31°, which is fairly constant throughout. The country-rock is mainly hornblende-granite.

The shoots have a decided pitch to the east, which was probably determined by the beds of hornblende-granite, which, as already stated, dip in that direction. The contents, below water-level, are usually altered country-rock, quartz, calcite (infrequent), with pyrite, chalcopyrite (rare), arsenopyrite (infrequent), marcasite, pyrrhotite (rare), sphalerite and galena.

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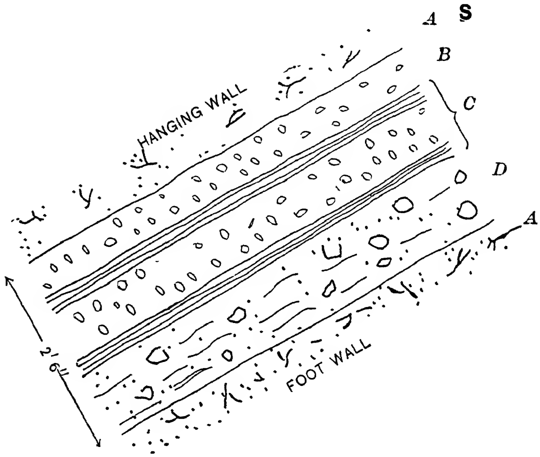
[21] Determined by Dr. Flett. The country-rock has been incorrectly described as syenite by F. P. Gamba (*Riqueza Mineral de la Republica de Colombia*, p 62 (1901). H. W. Nichols and O. C. Farrington state it to be an "andesite or a trachyte," but "the specimens examined were too much altered by the action of the vein-liquors for exact determination." The Ores of Colombia, *Field Columbian Museum, Publication No.* 33, *Geological Series*, vol. i, No. 3, pp 132, 133.

The galena, as a rule, is highly auriferous, pyrite much less so; the remaining pyritic minerals usually bear a certain proportion of gold, with the exception, perhaps, of pyrrhotite, which appears to occur only where the vein is poor.

Some free gold occurs in the vein, even below water-level. The bullion from the rich shoot, below water-level, averages a fineness of 609 gold and 358 silver.

The structure of the vein is a roughly-banded one; being generally composed of several layers of quartz and pyrites parallel to the walls.



A, Hornblende-granite; *B*, Solid quartz with patches of pyrite; *C*, Solid quartz with lines of pyrite, sphalerite and galena; *D*, Oxidized ore with crumbly quartz.

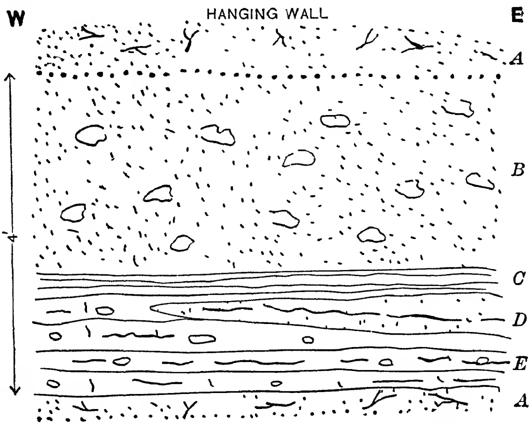
Fig. 1.—Cross-Section 2 Ft. Above the Fourth Level.

Fig. 1 is a sketch of the vein, showing the general structure, taken a few feet above the fourth or "day"-level. Next the hanging-wall is a layer of solid quartz, containing patches of pyrite. The center is formed of a band of solid quartz, with lines of pyrite, sphalerite and galena, distributed as shown; between these layers the quartz contains patches of pyrite only. Next the foot-wall is a layer of oxidized ore in crumbly quartz.

The Spaniards use the term *filón* (Fr. *filon*) for veins or lodes of large size, smaller ones being termed *veta*, *vena*, and the diminutives, *vetica*, *veticilla*, *vetilla*, *venilla*. In Mexico, and in Spanish-America generally, *veta* is used to designate a vein or

lode, *filón* being sometimes applied to stringers. Although in Colombia the word *veta* is also in common use, the Antioquian miner (Antioqueño) prefers the term *hilo* (lit. thread), calling a leader or branch, *aguja* (lit. needle).

Below water-level, an underlay branch, *aguja*, of the vein, *hilo*, where an ore-shoot, *clavo*, occurs, has an average thickness of about 3 ft.; the best ore, rich in sulphides, being generally next the foot-wall. On the hanging-wall there may be a selvage of clay, *urgue*, an inch or so thick, or there may be several inches of altered country-rock carrying auriferous pyrites, and



A, Hornblende-granite; *B*, *Carrancho*; *C*, Laminated quartz; *D*, Thin wedge of highly altered rock; *E*, Quartz, scattered with galena, and with pyrite in layers and bunches

FIG. 2.—LONGITUDINAL SECTION 2 FT. ABOVE THE FOURTH LEVEL.

some free gold, *carrancho*.[22] The hanging-wall joint, usually above this, is often seen to be in short waves or curves, as is illustrated in Fig. 9. Sometimes, however, the *carrancho* is not separated from the ordinary country by a defined joint, but is frozen thereto as shown in Fig. 2.

It may be mentioned here that the granite at the surface frequently weathers into large spheroidal masses or concretions, showing concentric structure, embedded in red clay (laterite). Such structure is said to be "typically due to curved surfaces

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[22] The Gold-Mines of the Remedios District, Republic of Colombia, by Frank Owen, *Transactions of the Institution o Mining and Metallurgy*, vol iv , p. 10 (1896)

of contraction,"[23] and it is not improbable that the hanging-wall of the vein has followed the curved lines of contraction in the unaltered eruptive rock, as having been those of least resistance at the time of its rupture.

Sometimes the concavities are filled with ore, and the curved surfaces show horizontal lines, not very clearly defined.

Below water-level the conglomerate occurs in patches, generally next the hanging-wall of the underlay branch, where the ore-shoot occurs, which yields from 1 to 3 oz. of gold per ton. The conglomerate sometimes appears to occupy a pre-existing cavity, but usually it is continuous with, and appears to merge insensibly into, the ordinary structure of the vein. It consists of rounded fragments of vein-quartz lying in a quartzose cement, which is impregnated with pyrite, galena and sphalerite.

A microscope-slide, prepared from a characteristic specimen, was kindly examined for me by Dr. Flett, whose remarks upon the specimen, taken down at the time, are here given.

"The slide shows numerous pieces of quartz which are full of fluid-cavities, but do not show any effects of metamorphism, and are probably all derived from vein-quartz. Here and there is seen also a much decomposed crystal of feldspar, but these are few The quartz fragments are usually rounded, and the larger fragments are more rounded than the smaller, and altogether they look as if they were water-worn The rock also contains pyrites and a brown mineral which is probably blende mixed with galena The matrix or cement of the rock consists of little fragments of quartz of various sizes, angular or sub-angular, with dark specks of magnetite and pyrites, and occasional spots of blende It is a water-worn conglomerate, probably silicified and impregnated with mineral matter."

The conglomerate sometimes contains small fragments of altered country-rock visible to the naked eye; and some of the larger pieces of quartz are angular or sub-angular. Most of the specimens collected show one or more broken portions of quartz crystals, sometimes transparent and sometimes opaque, up to half an inch in length, lying in the cement, which is the more remarkable as the quartz of the vein is crystalline, and vugs lined with crystals of quartz are of very rare occurrence. Moreover, although the vein is usually built up of bands of quartz, parallel to the walls, alternating, frequently, with layers of more or less altered country-rock, "comb-structure" is entirely absent, or, at least, has not hitherto been observed, and,

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[23] Grenville A. J. Cole, *Aids in Practical Geology*, 2d ed, p 89 (1893).

as the quartz layers in places appear to pass insensibly into country-rock on all sides, the probabilities are that the vein has been formed by gradual replacement or substitution of the latter—the probable agency having been thermal solutions which have ascended the original fracture.

Evidences of thermal action are quite common on the walls of the vein, as well as in the country-rock enclosed therein. One specimen of the rock, occurring on the foot-wall of the vein where it is rich, was examined by Dr. Flett, who says,

"The microscopic structure shows it to be utterly rotted, and it consists almost entirely of decomposed minerals, but it was no doubt originally a diorite-porphyrite, probably a hornblende-diorite-porphyrite. The probable agency of decomposition was hot water rising"

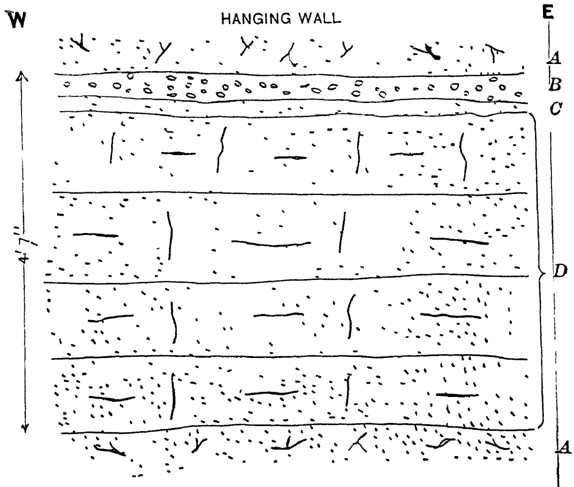
This highly altered rock, grayish-white in color, is scattered with cubic crystals of pyrite. In one place a thin wedge of it occurs in the main vein a few inches below what appears to be the hanging-wall joint of the lode, as is shown in Fig. 2. The laminated quartz, from 3 to 4 in. thick above the wedge, has a tendency to be in rounded fragments, but it is not very pronounced. Above the vein proper there is *carrancho*, as much as 2.5 ft. thick.

A thin layer of the same decomposed rock is shown in Fig. 3, forming the hanging-wall of the vein; 6 in. of hornblende-diorite-porphyrite separate it from the hornblende granite country-rock above. In this instance the vein proper is 4 ft. thick, and consists of layers of quartz of the usual structure spotted with pyrite, sphalerite and galena.

In another branch of the main vein, which occurs on the hanging-side, and immediately above the sixth, or adit-level, I have seen in one place from 2 to 3 in. of conglomerate with clay next the well-defined hanging-wall. Below this conglomerate the quartz is laminated for an inch or so in thickness, the rest of the vein being composed of solid white quartz with patches of pyrite,—the total thickness being about 2 feet. In a rise immediately above the last-named occurrence the vein is 1 ft. thick, and shows in one place from 2.5 to 3.5 in. of conglomerate, just below the decomposed hanging-wall, which merges into solid quartz both to the rise and dip.

A little further east in a stope, started from the same rise, a

very hard compact conglomerate is seen, 6 in. thick, on the hanging-wall, extending down the dip for a length of 6.5 feet. Below this point the conglomerate wedges out as shown in Fig. 4. To the rise it appears to merge gradually into the ordinary structure of the vein. Next the hanging-wall, which is here composed of thin layers of hornblende-granite, is a thin layer of blue clay. The hanging-wall itself is polished and slickensided with horizontal lines. If lines parallel with the dip ever existed they have been obliterated by later horizontal movements. The branch-vein at this place is 4 ft. thick, and



A, Hornblende-granite, *B*, Hornblende-diorite-porphyrite; *C*, Highly altered rock; *D*, Solid quartz, spotted with pyrite, sphalerite and galena.

Fig. 3.—Longitudinal Section, Showing Thin Layer of Decomposed Rock (*C*).

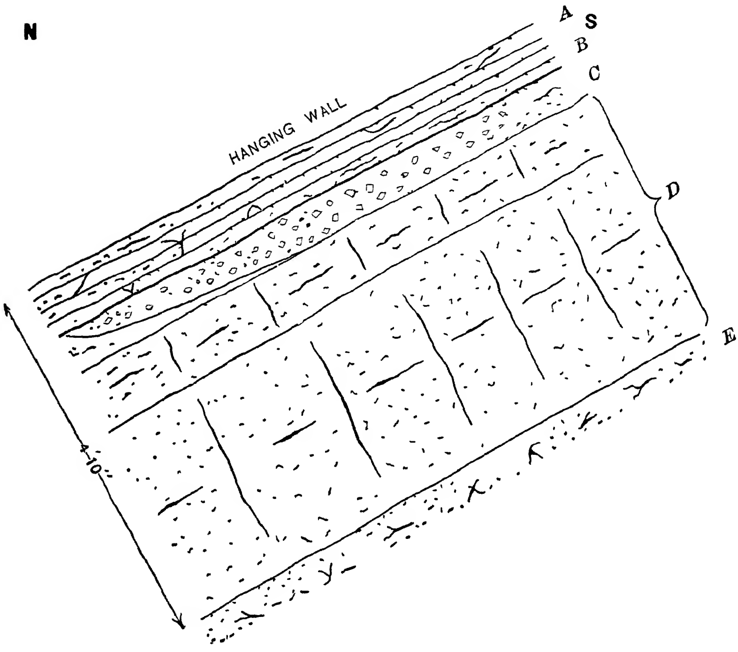
consists, below the conglomerate, of solid white quartz in two layers, as shown, spotted with pyrite. One specimen of the conglomerate shows an oblong fragment of hornblende-granite, highly charged with pyrite, measuring 1 by 1.5 in. in section, lying in the cement. The vein is crossed by joints which dip eastward; some of these are seen to pass through the conglomerate, and others do not.

The cement is quartzose, and some broken crystals of quartz are seen lying in it. It is fairly charged with pyrite, much more so than the solid quartz of the vein. A panning-test

was made of a few pounds of the conglomerate, which was found to contain several grains of comparatively coarse gold.

On the whole, the vein has a poor appearance, yet a milling-test yielded about 15 dwt. of gold to the ton.

About midway between the fourth and sixth levels, patches of conglomerate have also been observed in the stopes of the main vein, looking north, or in the direction of the dip, as



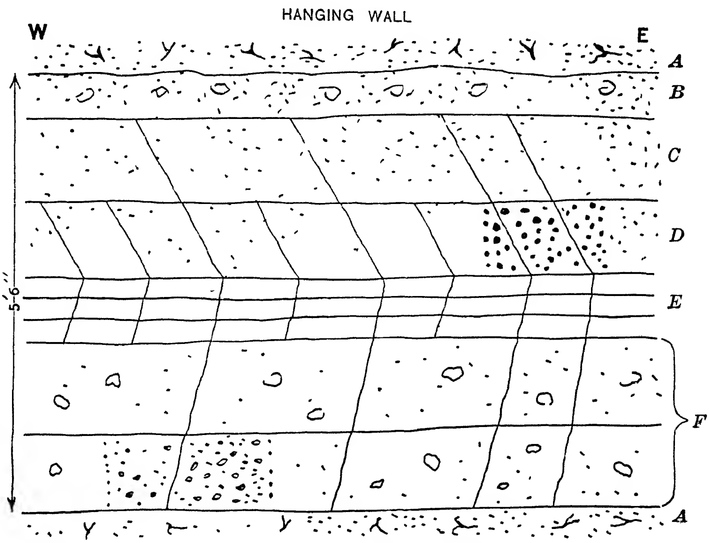
A, Hornblende-granite in thin layers (sheared), *B*, Fluccan of blue clay; *C*, Patch of conglomerate in quartz, *D*, Solid quartz spotted with pyrite; *E*, Hornblende-granite

FIG 4—CROSS-SECTION, SHOWING THE "WEDGING OUT" OF THE CONGLOMERATE

sketched in Fig. 5. One of these patches which occurred near the center of the vein measured 18 in. on the line of strike and was 12 in. thick. On either side it appears to merge imperceptibly into the ordinary structure of the vein. The other patch, about 2 ft. long and 1 ft. thick, was on the foot-wall and contained large lumps of conglomerate. The depth of the patches was not ascertained, but it probably does not exceed a few feet. The ore at this point, although above adit-level,

shows traces of oxidation only; it consists of pyrite, sphalerite and galena scattered in a hard quartz matrix. The vein is from 5 to 6 ft. thick and carries from 8 to 15 dwt. of gold per ton.

Some of the quartz fragments are of comparatively large size, up to 1 in. in diameter, but they are not all rounded; some being lenticular and others prismatic in shape, as if the latter had been broken off from layers of quartz measuring from 0.5 to 0.75 in. thick. Fragments of altered country-rock, a few opaque crystals of quartz, and patches of pyrite



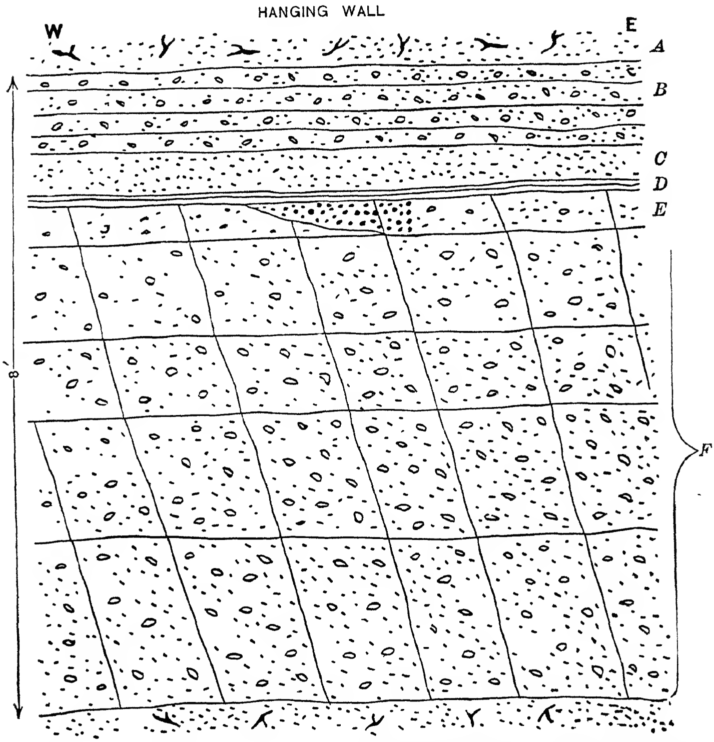
A, Hornblende-granite; *B*, *Carrancho*; *C*, Hard white quartz; *D*, Quartz with patch of conglomerate, *E*, Hard quartz with layers of pyrite, *F*, Hard quartz with patches of pyrite and conglomerate on foot-wall

Fig 5.—Longitudinal Section, in Stopes Between 4th and 6th Levels

are also seen lying in the cement. The term conglomerate-breccia would perhaps not inaccurately describe the occurrence.

In the same stopes, on the dip side of the section above mentioned, where the vein of low-grade value is 7 ft. thick, another patch of conglomerate 2 ft. long was seen, which was separated from the highly altered hanging-wall (the same rock that is shown in Figs. 2 and 3) by 2 in. of laminated quartz. A sketch of this structure is given in Fig. 6. On the east side,

the conglomerate, from 6 to 8 in. thick, merges imperceptibly into the ordinary structure of the vein. On the west side, however, it gradually wedges out as shown in the sketch. Cross-joints are seen in the vein, dipping at a high angle to the east, some of which pass through the conglomerate, and are



A, Hornblende-granite; *B*, Hornblende-diorite-porphyrite, with schistose structure (sheared); *C*, Highly decomposed, here and there forming a clay; *D*, Laminated quartz (mineralized); *E*, Mineralized quartz, with patch of conglomerate; *F*, Bands of solid white quartz, with spots and patches of pyrite.

FIG. 6.—LONGITUDINAL SECTION, IN STOPES BETWEEN 4TH AND 6TH LEVELS.

therefore of later date than the formation of the latter. The rest of the vein consists of bands of solid white quartz with spots and patches of pyrite.

The conglomerate is composed of small, rounded, elongated fragments of quartz in a quartzose cement, sprinkled with crystals of pyrite and galena. The upper surface, which is next to

the laminated quartz, is coated with pyrite in very small crystals, and is slickensided by a number of faint lines of friction. A portion of a slender transparent crystal of quartz, three-eighths of an inch long, lies in the cement.

As the vein is most probably a replacement one, it is difficult to conceive how the conglomerate originated. Movements in the walls, or subsidences due to gravitation, may have helped considerably in the formation of the patches of conglomerate and conglomerate-breccia.

There is evidence of movement having taken place in the walls, for normal or down-thrust faults are not uncommon; when these cross the vein at right-angles, or obliquely, the displacement is *nil*, or only of slight extent, varying from a few inches to several feet; but where the vein has a NW—SE. strike it is coincident with a fault which dips in a contrary direction to the vein, or SW. 73°. The fault cuts the vein off entirely along the line of intersection, which is just above the fourth level, and there is evidence here that the portion of the vein to the rise has slid 121 ft. down the hanging-wall of the fault. The latter, however, lies 600 ft. east of the ore-shoot in which the conglomerate, first described, occurs. It has on its foot-wall side from 6 to 8 in. of breccia, some of the fragments of which are distinctly rounded. In one part there is conglomerate, the pebbles of which are very small in size, but the cement is similar to that occurring in the vein, and, here and there, crystals of pyrite are seen lying in it. The conglomerate is quite barren, whereas that found in the lode is distinctly gold-bearing—the gold usually being coarser than that found in the rest of the vein. One surface appears to be worn smooth by rubbing, and some faint lines can also be detected, which are probably scratches produced by friction.

Besides the selvage, or fluccan, already mentioned, lines of friction are not uncommon on the hanging-wall. These lines are usually not quite parallel with the dip. Other lines are horizontal, seeming to show that there has been some horizontal thrusting as well, but insufficient to produce reversed faults. (I have seen one example of a reversed or overlap fault in a vein of the Providencia mine, which adjoins that of Sucre.)

There is evidence, here and there, that considerable pressure,

generally local in extent, has been applied to the vein, probably long after its formation.

In one place, a few yards above the fourth level, the vein in

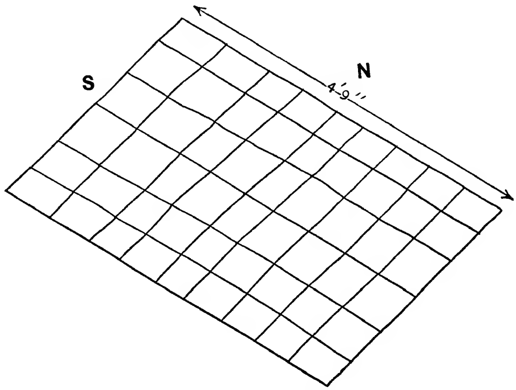
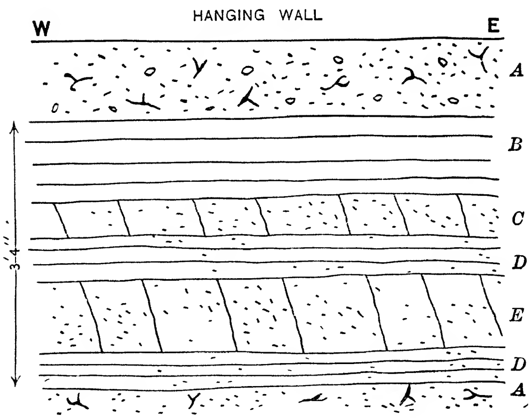


FIG 7.—CROSS-SFCTION, A FEW FEET ABOVE 4TH LEVEL.



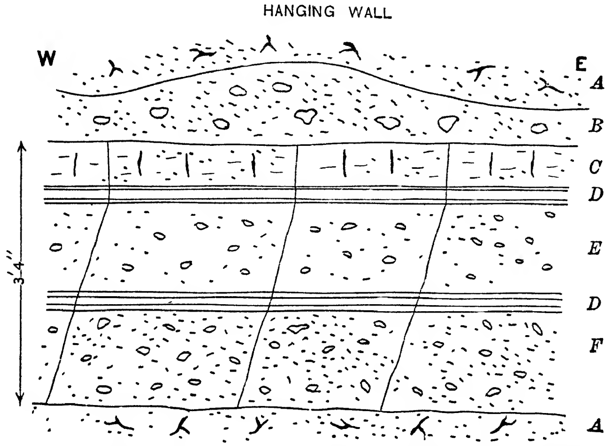
A, Hornblende-granite, mineralized country-rock; *B*, Laminated quartz; *C*, Quartz jointed and crushed; *D*, Quartz with layers and spots of pyrite, sphalerite and galena.

FIG. 8.—LONGITUDINAL SECTION, SHOWING ALTERNATION OF SHATTERED AND SOLID QUARTZ.

a rise consists of white barren quartz, which is completely shattered by a number of joints, which cross the vein somewhat obliquely, thereby breaking it up into a number of rhomboidal

pieces, as shown in Fig. 7. Below this point, no cross-joints are seen, and the vein is gold-bearing to a certain extent, yielding an average of about 5 dwt. of gold to the ton.

In this instance the pressure was probably applied nearly at right-angles to the dip of the vein—in other words, it was more or less vertical. More frequently it has been lateral, and has crushed or cleaved the vein nearly at right-angles to the strike. Here and there layers of quartz, so shattered, alternate with others that are solid. Fig. 8 illustrates this structure.



A, Hornblende-granite; *B*, *Carrancho*, spotted with pyrite; *C*, Solid quartz, spotted with pyrite; *D*, Laminated quartz (mineralized); *E*, Solid white quartz (mineralized); *F*, Quartz with spots and patches of pyrite, sphalerite and galena (pay-streak)

FIG. 9.—LONGITUDINAL SECTION, IN THE RICH SHOOT ON THE BRANCH VEIN.

In one place, in the rich shoot on the branch vein, similar joints cross the lode, but in the lower or comparatively soft part of the vein, the joints dip W. 75°, while in the upper or harder portion they dip W. 86°, showing a bending or refraction of 11°, as shown in Fig. 9.

In the stopes between the fourth and sixth levels, where patches of conglomerate-breccia occur, cross-joints are also seen, which are few in number in the very hard layers of quartz—moreover, in one place in the upper portion of the vein, the joints dip east at a high angle, whereas in the lower portion the dip is in a contrary direction or west, as is illus-

trated in Fig. 5. These joints or rough cleavage-planes, also seen in Fig. 6, are not traceable in the *carrancho*, or decomposed layer of rock, clay and small lumps of quartz next the hanging-wall, and are not always traceable in the very hard layers of quartz.

On the whole, I am inclined to think that the vein was crushed in places by downward movements in the walls, or in the vein itself. The occurrence of broken crystals of quartz in the cement seems to indicate, that, at one time, cavities or vugs existed in some of the spots where the conglomerate is now found. Where such cavities exist, a vein would be more apt to be crushed and broken up under great stress than where it is solid. The occasional occurrence of laminated quartz,—quartz in thin layers,—has already been noted. This mineral has probably replaced country-rock which has been sheared by the downward movement. Afterwards, hot water continuing to rise, and gradually to replace the remaining layers of country-rock in the vein, would, on entering the shattered masses, have a certain freedom of movement therein, whereby many of the fragments would become further rounded, both by mechanical and chemical action, and finally be cemented together by quartz and other minerals—thus forming solid conglomerate or conglomerate-breccia.

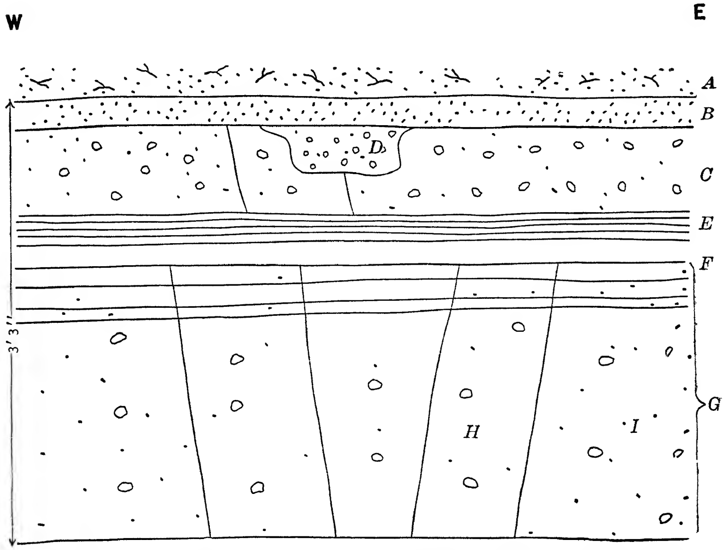
The cross-jointing or cleavage is clearly more recent than the general formation of the vein and the containing conglomerate, but that mineral depositions have been going on of later date even than the cross-joints, also appears extremely probable, for pyrite in the vein is seen in places to follow the cross-joints, or to have been deposited in lines coincident with them, and therefore oblique to the strike of the vein.

Postscript:*—Since writing the above paper several patches of conglomerate, in addition to those already described, have been encountered in stoping down the Sucre lode and its hanging-wall branch. Some of these are of sufficient interest to be recorded.

Fig. 10 is a longitudinal-section, illustrating what is seen in the under-hand stopes of the main vein, a little east of the section shown in Fig. 5. Here, a small patch of conglomerate, 9 in.

* Received February 4, 1904.

long by 4 in. thick, occurs on the hanging-wall side, *A*, below the *carrancho*, *B*, of an 8-in. layer of solid white quartz, *C*, containing patches of pyrite and a patch of conglomerate, *D*; below the quartz is a layer of quartz and sulphides, *E*; then comes a thin layer of white unmineralized quartz, *F*. On the foot-wall side there is a streak of solid quartz, *G*, 2 ft. thick, well mineralized above, and with patches of pyrite below. The actual foot-wall of the vein was hidden by broken ore. The



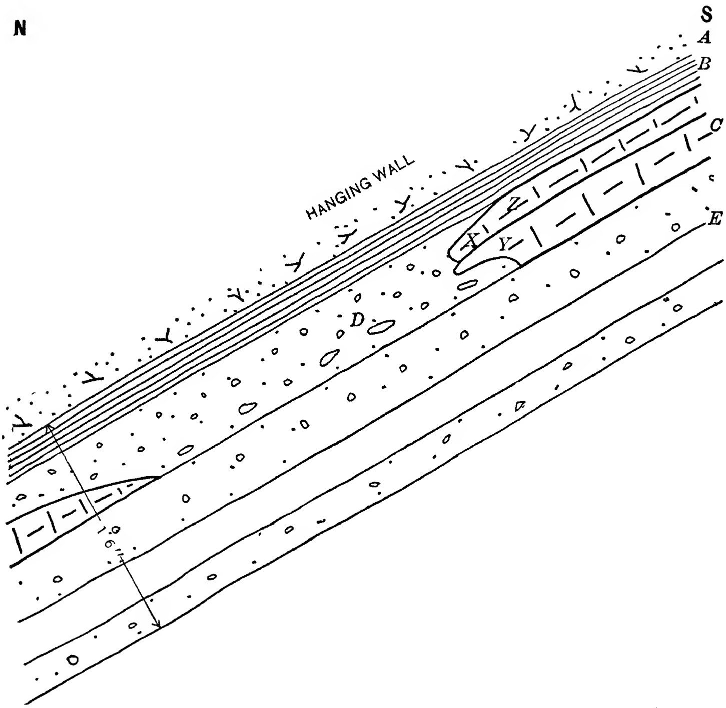
A, Hornblende-granite in rolls; *B*, *Carrancho*, next to hanging-wall; *C*, Solid white quartz spotted with pyrite, and with patch of conglomerate (*D*); *D*, Conglomerate; *E*, Well-mineralized quartz; *F*, Non-mineralized quartz; *G*, Solid white quartz; *H*, *I*, Joints crossing the vein somewhat obliquely.

FIG. 10.—LONGITUDINAL SECTION, IN STOPES BETWEEN 4TH AND 6TH LEVELS

conglomerate is very clearly defined, and does not merge gradually into vein-quartz. The contact is an irregular, but distinct, line. The layer, *G*, has several joints crossing it, dipping as shown. The joints, *H* and *I*, cross the vein somewhat obliquely. Similar radiated jointing has been observed in other portions of the vein, and was probably produced by local pressure. No joints are visible in *E* and *F*, but there are a few joints in *C*, dipping east. One of these partly penetrates the

conglomerate and has broken one of the larger pebbles into two pieces which were slightly faulted by it. There appears to be fragments of broken crystals of quartz lying in the siliceous cement, but these are not so clearly defined as those found in other instances quoted earlier in this paper.

A very instructive example, sketched in Fig. 11, occurs in



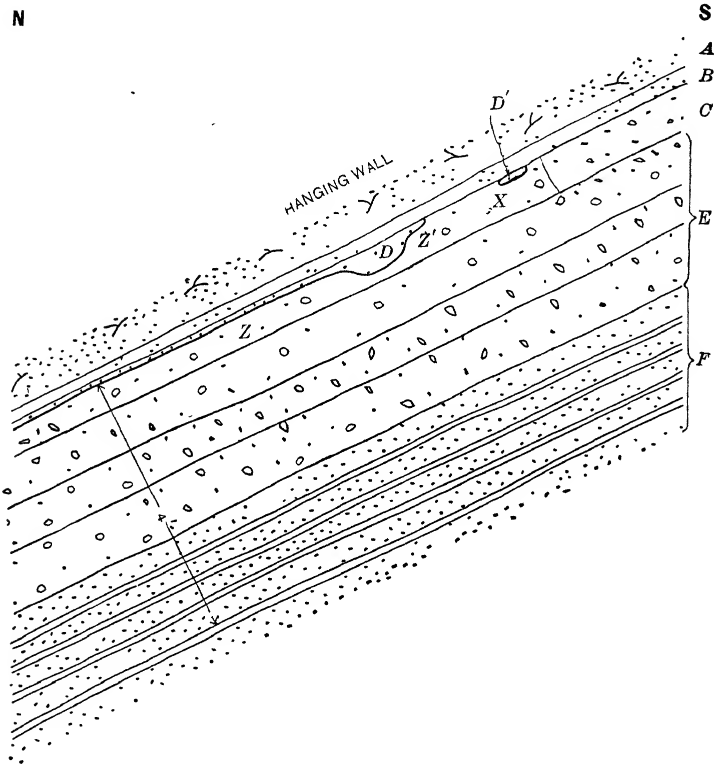
A, Hornblende-granite; *B*, Schistose hornblende-granite; *C*, Two layers of quartz which have been broken off, showing conglomerate (*D*) below; *D*, Conglomerate; *E*, Solid white quartz with patches and spots of pyrite.

X, *Y* and *Z* refer to the position of the conglomerate surrounding the end of the quartz-break.

FIG 11.—CROSS-SECTION, A FEW FEET EAST OF THAT SHOWN IN FIG. 4.

the over-hand stopes on the hanging-wall branch, a few feet to the east of that represented in Fig. 4. The patch of conglomerate is about 6 ft. deep, being 6 in. thick in the upper portion and gradually wedging out below. The contact between the conglomerate and the quartz-vein to the rise is very clearly defined. It is seen that the portion of the vein next the hang-

ing-wall consists of two layers of quartz, 2 in. and 4 in. thick, respectively. The conglomerate overlaps the 2-in. layer from *X* to *Z*; the latter was evidently bent downwards by pressure exerted at some time, and was abruptly broken off at *X*, while at *Y* the fracture was irregular. It is worthy of note that the



A, Hornblende-granite; *B*, *Carrancho*, next to hanging-wall; *C*, Hard white quartz with patch of conglomerate (*D*); *D*, and *D*[1], Conglomerate; *E*, Bands of quartz with patches and spots of pyrite; *F*, Foot-wall (hornblende-diorite-porphyrite) highly altered next to vein and seamed with quartz.

X, and *Z* and *Z'* refer to the position of the conglomerate patches.

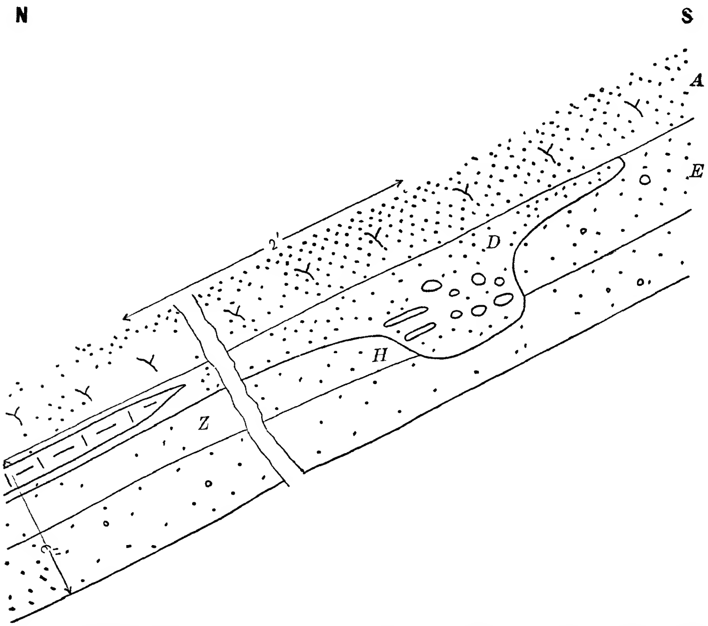
FIG. 12.—CROSS-SECTION, JUST ABOVE THE INTERMEDIATE LEVEL.

larger quartz pebbles of the conglomerate are ranged along the foot-wall side of the latter, as depicted in the sketch, and that next the hanging-wall proper there is a thin layer of crushed country-rock, consisting of schistose hornblende-granite.

A crystal of opaque quartz was visible in one place in the

cement of the conglomerate; other crystals may have been present, but were not noticed, as the ore was blasted down in the ordinary course and sent direct to the mill.

A few feet below the last example, and just above the intermediate level (*zapa*), driven eastwards in that section of the mine, another patch of conglomerate occurs, as shown in Fig. 12. Next the hanging-wall (hornblende-granite) there is a layer of *carrancho*, 4.5 in. thick in the upper part of the section,



A, Hornblende-granite; *D*, Conglomerate; *E*, Bands of quartz with patches and spots of pyrite; *H*, Flat bands of quartz in conglomerate

FIG. 13.—CROSS-SECTION. ENLARGEMENT OF A PORTION OF FIG. 12.

thinning away to 1.5 in. lower down. Below this is a layer of solid white quartz, 6 in. thick. Near *X*, a joint crosses this layer perpendicularly, and, just below it, is a thin layer of conglomerate, *D′*, for a depth of 7 inches. At *Z′*, is an irregular patch of conglomerate, *D*, 8.5 in. deep and about 4 in. thick. To the rise, the conglomerate overlaps the quartz-layer for 6 in.; to the dip it is continued as a thin layer 2 in. thick to the point *Z*. From *Z*, downwards, it encloses a thin streak of quartz which is wedge-shaped above.

An enlargement of these conglomerate patches, given in Fig. 13, shows the position of two flat pieces of quartz, *H*, which lie in the cement, and were evidently broken off from the quartz-layer at that point. In addition to these, are seen several other comparatively large fragments of quartz, but more or less rounded, as shown.

The vein below the upper quartz-layer consists of several bands of quartz, well mineralized, lying on altered porphyrite, 33 in. thick, seamed with white quartz, which here forms the foot-wall.

In all the instances observed, the conglomerate was evidently formed *in situ*, and probably, in the main, by the sliding-down of the hanging-wall. Cavities no doubt once existed in the vein at certain points, so that the latter, unable to withstand the downward stress, was crushed into fragments. The angles of the larger fragments would be taken off to a certain extent by attrition, the rounding process being completed by the later inflow of thermal waters, which also cemented the pebbles together, finally converting the whole into one solid mineralized mass.

If we regard the vein as an inclined plane, the pressure of the sliding superincumbent mass of rock, or the component perpendicular to the plane, must have been enormous, seeing that the inclination or slope is only from 20 to 30°, whereby weak parts of the vein would invariably have been crushed, not only on the hanging-wall side, but probably also in the center and foot-wall side. (See Fig. 5.)

In the neighborhood of the conglomerate, shown in Fig. 11, joints were observed in the hanging-wall, perpendicular to the plane of the vein, and which appear to be a continuation of these seen crossing the latter. Some of these joints are slickensided in a vertical direction. These joints were probably produced by lateral pressure, which occurred long after the sliding-down of the hanging-wall.

The Copper-Deposits at San Jose, Tamaulipas, Mexico.

BY PROF J F. KEMP, COLUMBIA UNIVERSITY, NEW YORK, N. Y.

(Washington Meeting, May, 1905)

CONTENTS.

I. Introduction.*

1. *Situation.*—From Monterey in the State of Nuevo Leon, the Sierra Madre mountains stretch away to the southeast and present a steep front to the northeast. The Monterey and Mexican Gulf railway, which connects Monterey with Tampico, follows their general line with its road-bed a few miles out from the foothills. At a distance of 100 miles from Monterey it passes through the town of Linares, and from Linares one can see far away to the southeast the peaks of another group of mountains rising from the general plateau and forming a more eastern

* For much assistance and cordial interest in the preparation of this paper, I desire to express my acknowledgments to Mr. E. D. Self, general manager of the mines at San Jose, and to Mr. W. H. Nichols, Jr., president of the San Carlos Copper Co.

uplift distinct from the main mountain system. The outlying group is the San Carlos range, and is one of extreme geological interest because of its nephelite-syenites and rare types of associated eruptives. These have been recently described by George I. Finlay,[1] who was my companion during the trip upon which the observations for the present paper were made. The San Carlos mountains extend east and west, and are about 15 miles long. Their highest point, Pic de Diablo, which is just south of San Jose, has been determined by aneroid to be 6,000 ft. above sea-level. The peaks are rugged, and have pre-

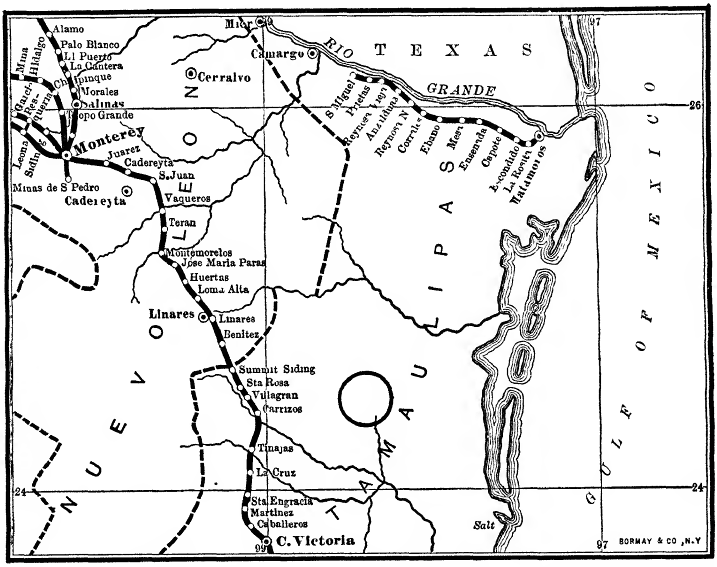


FIG. 1.—MAP OF NORTH-EASTERN PART OF MEXICO, THE CIRCLE SHOWING THE LOCATION OF THE SAN JOSE DEPOSITS.

cipitous escarpments, surrounding inner amphitheatres. They are clothed with a noble growth of pines in the upper portions and receive enough precipitation to support a number of brooks, which, however, except in the wet season or immediately after heavy storms, are lost in the gravel of the arroyos below. The range soon dies out to the east of San Jose. Its main mass lies to the south.

San Jose, the little town where the copper-mines are located,

[1] The Geology of the San Jose District, Tamaulipas, Mexico, *Annals of the New York Academy of Science*, xiv., 247–318, 1904. Eleven plates.

is situated in a valley on the northern side of the mountains. Its arroyo leads out to the northeast, and the pass to the south goes around the eastern extremity of the nephelite-syenite, over a divide and south to the town of San Carlos. San Jose is about 40 miles from Linares, with which it is connected by a good road across a plain covered with the familiar growths of cactus and mesquit, so characteristic of northern Mexico. The construction of a railway between San Jose and Linares is nearly finished.

2. *Geology.*—From Linares to San Jose, the country rocks are generally concealed by the soil, but at the ford over the creek near Pretil, shales are to be seen in which a brief search failed to reveal fossils. As one nears the mountains, however, heavy strata of limestone rise gradually until the road follows the arroyo in a quite narrow canyon with cliffs on either side. Finally, having crossed the strata of outwardly dipping limestone, the town of San Jose is met, resting upon the carved and eroded remains of a great exposure of eruptive rock.

Detailed study shows, however, that the eruptive area is surrounded on all sides, except the south, by the limestones, which rest upon the porphyry and dip away outwardly. There is no doubt, therefore, that we have to do with an eroded laccolith of eruptive rock, which has heaved up the limestones into their present positions and which has been cut off on the south by the nephelite-syenite, probably along a fault. These features are shown on the geological map, Fig. 2, reproduced with a few modifications from Dr. Finlay's paper in which it forms Plate VIII.

The altitude of the village of San Jose is approximately 2,250 ft. above sea-level. The hills of porphyry within the laccolithic valley rise from 500 to 600 ft. higher, are steep and obviously present what physiographers call, a "young" topography. A bore-hole sunk since my visit shows the laccolith to be over 1,000 ft. thick at the Santo Domingo mine. The surrounding ridge of limestone, and on the south the syenite, reach the elevations marked on the map at the several stations. The limestone rim thus rises at its lowest summit 750 ft. above the valley, and at its maximum 1,550, while the nephelite-syenites attain heights of from 2,500 to 3,000 ft., and at the Pic de Diablo (not shown on the map) 3,750 ft. above it.

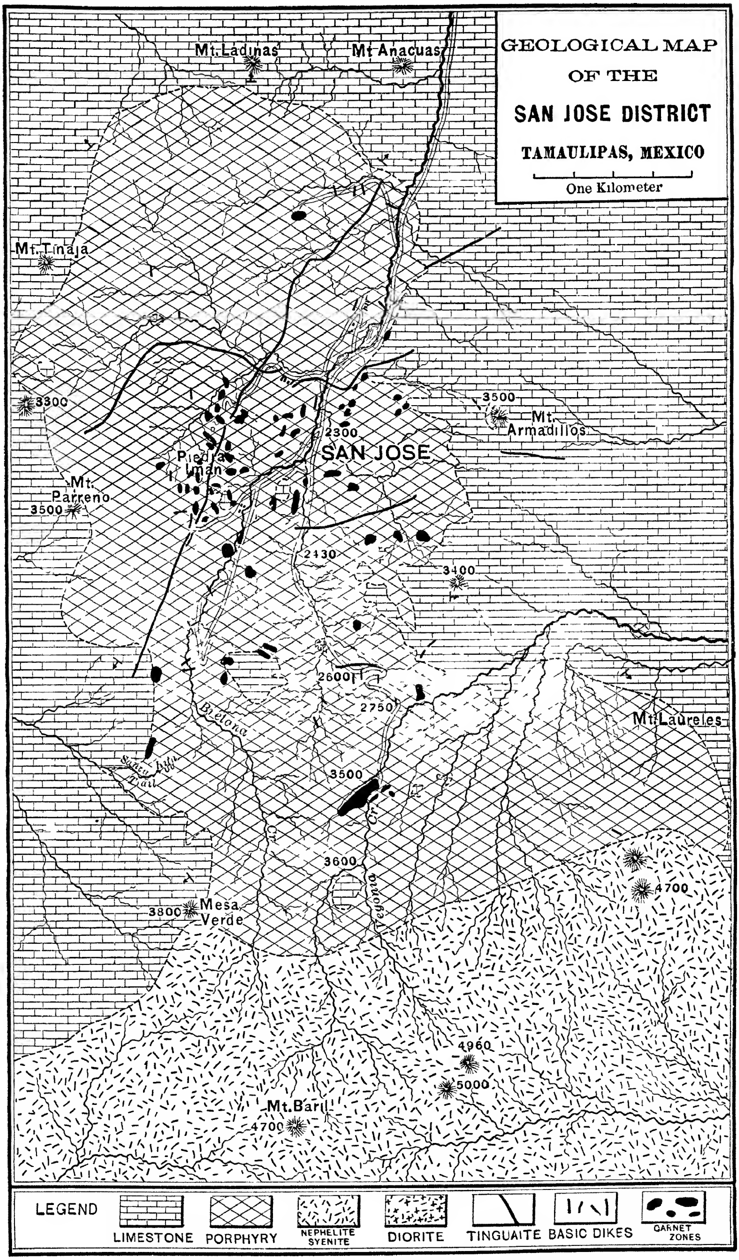


FIG. 2.—GEOLOGICAL MAP OF THE SAN JOSE DISTRICT.

The limestone is a rather fine-grained bluish variety, where it has not been exposed to contact-metamorphism. It is believed to be Cretaceous and to belong to the very thick formation which is such a prominent feature of northeastern Mexico. It is almost entirely devoid of fossils. I only succeeded in finding one poorly preserved *belemnite* and one larger form resembling an *Exogyra*, the latter in a rock altered to a white marble by the neighboring eruptive. R. T. Hill has reported that a formation probably the same as this limestone, but in the valley of the Miquehuana, which is west of Victoria and southwest from San Jose, though still in the state of Tamaulipas, is 20,000 ft. thick.[2] As many earlier observers have remarked, the limestone most closely resembles in its appearance the Paleozoic limestones of the eastern United States and especially the Cambro-Silurian ones of the Great Valley, which, like the Mexican occurrence, are singularly lacking in fossils. Near San Jose we have neither the top nor the bottom of the series, but there are certainly from 1,000 to 2,000 ft. exposed. The limestone is well bedded and it is at times provided with black flint or chert. From the central eruptive area it dips radially outward, and is therefore in the form of the great eroded dome, so characteristic of laccolithic intrusions. On the south, however, where the mountains of nephelite-syenite cut off the limestone, this structure does not hold, and it is believed that the nephelite-syenite was elevated by faulting before the intrusion of the laccolith.

II. Eruptive Rocks.

The eruptive rocks are of exceptional scientific interest because of the rare types represented. They will be briefly described in their order of age from the oldest to the latest, so far as the succession can be made out. The following varieties are present. Irregular masses of nephelite-syenite and gabbro; the laccolith of diorite-porphyry; about 50 dikes in all of tinguaite, diabase, camptonite and vogesite; finally a surface-flow of basalt. While some of these names are not generally familiar, a few explanatory sentences under each, as taken up below, will serve to tie them up to varieties which have long been well established.

[2] R. T. Hill. The Cretaceous Formations of Mexico, etc, *American Journal of Science*, April, 1893, p. 309.

1. *Deep-Seated Eruptives.*

(a) *Nephelite-Syenite.*—The oldest of the eruptives is the nephelite-syenite which constitutes the high peaks to the south. It is a rather coarsely crystalline rock, which for all practical purposes may be likened to a granite. It is a peculiar variety of syenite in that it contains the mineral nephelite. The rock is sometimes nearly pure feldspar and nephelite, and is light in color. Again, it has, with these two, more and more black hornblende and pyroxene, until it becomes dark gray. Almost always honey-yellow titanites are visible to the eye. The several varieties have been fully described by Dr. Finlay.

The following chemical analysis, made by Dr. Henry S. Washington, illustrates the composition of one of the varieties:—SiO_2, 58.40; Al_2O_3, 20.25; Fe_2O_3, 1.78; FeO, 2.41; MgO, 0.49; CaO, 3.11; Na_2O, 7.01; K_2O, 5.39; H_2O (110°), 0.27; H_2O (ign.), 0.57; TiO_2, 0.25; P_2O_5, 0.20; SO_3, 0.06; Cl_2, 0.02; total, 100.21 per cent. This shows a typical nephelite-syenite rich in feldspar. Dr. Finlay estimated the percentage-composition of the several minerals by measuring areas in thin sections, and for three varieties of the rock, his results, showing the increasing amounts of the dark silicates, are as follows:

	Percentage of Areas	Percentage of Areas.	Percentage of Areas.
Orthoclase,	60 0	12.0	5 6
Plagioclase,	5.0	. .	.. ...
Nephelite,	25.0	18 0	13 2
Augite,	1.0	23.0	13.9
Hornblende,	.	40.0	60 5
Biotite,		...	2 2
Magnetite,	8 0	2 7	0.4
Titanite,	0 7	2.0	2 8
Apatite,	. .	1 2	1 4
Total,	99 7	98 9	100 0
Average size of grain,	0.36mm.	0.2mm	0 16mm.

The coarsely crystalline texture of the syenite proves it to be a rock which has consolidated far below the surface, slowly and under pressure. Its present elevated position is believed to be due to faulting, as earlier stated. It is older than the porphyry, but whether it is older than the limestones was not determined, because in no place could the two be found in con-

tact. Whether, therefore, the syenite formed an old land-area and shore along which the limestones were laid down on the sea-bottom, or whether it was intruded into them, and later faulted into its present position, we do not know. It is possible, however, that the question could be solved at the western end of the range.

(b) *Gabbro.*—This rock was found in three places, two near each other and mapped as one along the road from San Jose to the Vegonia mine, and one in a gulch northwest of the village. Recent work has shown the former to be somewhat more extensive than is given on the map. The exposures are deeply weathered and rusty brown. The fresh specimens are granitoid in texture, medium grained and dark grey. The constituent minerals are plagioclase, biotite, augite, titanite, magnetite, apatite, pyrite and zircon. This rock was called a diorite by Dr. Finlay on account of its moderately acidic feldspar, but in order to be clear to readers more especially familiar with rock-names employed in mining-districts and on account of the preponderating augite, it is here called gabbro. Two analyses of slightly differing varieties, made by Dr. Finlay, are:—SiO_2, 45.75 (48.49); Al_2O_3, 18.51 (18.99); Fe_2O_3, 6.55 (9.59); FeO, 6.02 (1.00); MgO, 5.06 (5.05); CaO, 11.85 (10.78); Na_2O, 3.41 (3.47); K_2O, 2.35 (1.42); Na_2O, trace (nil); H_2O (100°), 0.06 (0.10); H_2O (ign.), 0.20 (0.55); total, 99.76 (99.44) per cent.

These analyses show the rock to be a rather basic variety, but one which does not differ in any extraordinary degree from those of many gabbros. The syenite and gabbro are two characteristically deep-seated rocks.

2. *The Laccolith.*

The next in order of formation is the rock constituting the laccolith, which is here described under the general name diorite-porphyry. This eruptive combines the features of a deep-seated rock with those of a dike or sheet. It is visibly porphyritic, but the ground-mass, as often happens in laccolithic types, is subordinate and it may almost, if not quite, disappear. The rock therefore shades texturally into a very feldspathic diorite, and from the diamond-drill cores and some of the deeper exposures it can with difficulty be separated, by the eye alone, from the whiter varieties of syenite. The rock is

named in accordance with the underlying conception, that igneous varieties belonging to the andesite-diorite series vary from glassy and felsitic surface-flows of true typical andesites; through porphyritic varieties with increasingly abundant phenocrysts—the andesite-porphyries of the dikes and sheets—on through those with less and less ground-mass—the diorite-porphyries, in laccoliths and stocks;—to the granitoid diorites in the batholiths and deep-seated masses. As the phenocrysts are very abundant and the ground-mass almost disappears in most of the exposures of the laccolith, diorite-porphyry best describes the rock. The name andesite was used by Dr. Finlay, and while I regard with misgivings any change in a nomenclature, already, although unavoidably confusing, the term diorite-porphyry is coincident with the usage of Whitman Cross in the folios and papers on the San Juan region of Colorado, where analogous laccoliths occur in many mining-districts. It is hoped that it will therefore be most significant to readers interested in mining-geology.

The diorite-porphyries are light yellow to bluish-gray in color and vary by insensible gradations from more basic to more acidic facies. They contain plagioclase, orthoclase, augite, biotite, magnetite, titanite, zircon, and, at times, quartz in considerable quantity. The ground-mass is fully crystallized and the contrasts are much less between it and the phenocrysts than are usually seen in surface-flows. But this relation always holds in the laccoliths and intruded sheets as all observers are well aware.

An analysis, made by Dr. Finlay, gave the following results: SiO_2, 62.31; Al_2O_3, 18.63; Fe_2O_3, 2,38; FeO, 1.33; MgO, 0.60; CaO, 5.91; Na_2O,4.97; K_2O, 3.52; P_2O_5, 0.07; H_2O(110°), 0.16; H_2O (ign.), 0.07; total, 99.95 per cent.

This analysis indicates a rather acidic variety. Column I. of the analyses on the following page gives the percentage-composition of the several minerals obtained by recasting the analysis. Column II. gives the percentage-composition of a still more acidic variety, a dacite-porphyry, obtained by measuring the diameters of the minerals in thin sections.

No biotite is tabulated under column I., because, although present in very small quantities, its complicated composition prevents its calculation.

Percentage-Composition of a Dacite-Porphyry.

	I	II
	Per Cent	Per Cent
Plagioclase,	60.0	32 0
Orthoclase,	20.6	25.0
Pyroxene,	6.6	16.0
Magnetite,	3.5	6.7
Quartz,	8 9	17 0
Biotite,	.. .	2.4
Accessories,	.....	0 9
Total,	99.6	100.0

The diorite-porphyry is the most important rock connected with the ore-formation, since it has produced the garnet-zones and has apparently occasioned the introduction of the ore, as will be later described. Messrs. Aguilera and Ordoñez, who have published a short note about this rock and its contact-zones, speak of it as an andesitic diorite.[3]

Where exposed near the contact-zones, the diorite-porphyry is at times supplied with pyrite which appears throughout the rock and which follows the innumerable tiny fissures ramifying through it in every direction.

The diorite-porphyry is found in the great laccolithic mass and also as innumerable dikes, penetrating the gabbro and especially the limestone, where the latter has been opened up in the mines. It constitutes the greater part of the San Jose valley, its unbroken extent being chiefly prevented by the inclusions of limestone which resemble islands in the midst of the eruptive mass.

It may be that there is more than one intrusion of the dioritic rock. Considerable range in mineralogy is exhibited, and while no positive field-evidence could be secured, and while the amount of the varieties must be small as compared with the main mass, yet the possibility may be considered.

The diorite-porphyry is later in age than the gabbro, since it cuts the latter in dikes. It is also later than the syenite, since along the contacts it shows the effects of chilling, and becomes denser.

[3] Bosquejo geológico de Mexico, *Boletin del Instituto geologico de Mexico*, Nos 4, 5, 6, p. 222 (1897).

3. *Dikes.*

(a) *Tinguaite.*—Dikes of this interesting rock cut the diorite-porphyry in every direction, and one in particular runs clear across the valley from limestone-wall to limestone-wall. Tinguaites are dense, dark-green rocks closely allied to phonolites, but containing the soda-pyroxene aegirite in great abundance, together with nephelite and orthoclase. A little plagioclase, titanite, magnetite, and in some varieties a great deal of analcite, complete the list of the minerals. Fine phenocrysts of orthoclase are sometimes abundant, but again the rock appears as a dense, green, felsitic one, and then has analcite as a rule.

Two analyses of the analcite-tinguaites, one made by H. S. Washington, the second, by G. I. Finlay, are as follows:—SiO_2, 52.83 (49.42); TiO_2, 0.16 (not det.); Al_2O_3, 20.70 (22.99); Fe_2O_3, 2.84 (2.70); FeO, 1.19 (1.89); MgO, 0.41 (0.45); CaO, 1.00 (2.59); Na_2O, 9.94 (9.63); K_2O, 4.87 (4.21); H_2O (110°), 0.37 (not det.); H_2O (ign.), 5.28 (5.73); P_2O_5, 0.03 (not det.); Cl, 0.06 (not det.); total, 99.68 (99.61) per cent.

The tinguaite dikes have been intruded after the formation of the ore and the garnet-zones. They cut the latter and are met in several places in the mines. They also appear as far as 20 miles away from the syenite, both toward San Carlos and toward Linares. Mr. Self concludes that these dikes become more abundant as one leaves San Jose in each of these directions. In other parts of the world, tinguaites have proved to be characteristic associates of nephelite-syenites, and it is quite natural that they should occur near San Jose. So far as we know, they do not cut the syenite, but are limited to the surrounding rocks.

(b) *Camptonite.*—In great contrast with the green dikes of tinguaite are a number of dark basaltic habit, which display long, black, slender prisms of hornblende on fresh fractures. They proved, on microscopic examination, to be the basaltic rock whose chief dark silicate and predominant mineral is chestnut-brown hornblende, and which contains also a little augite, plagioclase, magnetite and apatite. An analysis by Dr. Finlay yielded—SiO_2, 42.49; Al_2O_3, 17.68; Fe_2O_3, 5.12; FeO, 5.90; MgO, 5.28; CaO, 15.81; Na_2O, 4.29; K_2O, 2.97; H_2O, 0.38; total, 99.92 per cent.

The camptonite is thus a very basic rock. Elsewhere it is a

rather characteristic associate of nephelite-syenite, and its occurrence at San Jose is quite in accord with the general rule.

The camptonites cut the nephelite-syenite, the diorite-porphyry and the limestone. They are also later than the ore. No intersections have been found which would establish their relative ages as compared with the other dikes.

(c) *Vogesite.*—A 4.5-ft. dike of this interesting rock has been found, which consists chiefly of orthoclase, hornblende and augite, but there are also small quantities of magnetite, plagioclase, titanite and biotite. It is practically a very basic syenite of which hornblende makes up the major part of the rock.

(d) *Olivine-Basalt.*—One other dike of olivine-bearing basalt was found by Dr. Finlay in the syenite area five miles south of San Jose. It has, however, no connection with the ores.

4. *Surface-Flow.*

Basalt.—There is also a remarkable surface-flow of basalt which comes out of the eastern side of the San Carlos mountains, in the syenite-area, and extends for 4 or 5 miles down the Arroyo Grande. It is scoriaceous and still not greatly reduced by erosion. No cone is associated with it, and it seems to be a fissure-eruption. It is the last outbreak in the region. The rock is porphyritic and consists chiefly of plagioclase, augite and magnetite, with smaller amounts of biotite, titanite and glass. The habit is basaltic. An analysis by G. I. Finlay yielded,—SiO_2, 48.03; Al_2O_3, 20.98; Fe_2O_3, 7.06; FeO, 4.51; MgO, 4.43; CaO, 9.54; Na_2O, 3.28; K_2O, 1.99; H_2O (110°), 0.21; H_2O (ign.), 0.40; total, 100.43 per cent.

This analysis indicates a quite normal olivine-free basalt. The outbreak had nothing to do with the ores and is 5 or 6 miles distant from the nearest mine.

III. Contact-Effects.

The contact-effects are limited to the borders of the diorite-porphyry and the limestone, and they are variable in their intensity. The starting-point in their study is the composition of the unchanged limestone, because from this, one may infer whether silica and the bases have been added in the metamorphism or whether we are dealing with the rearrangement and crystallization of materials already in the limestone itself.

Samples have been very kindly furnished me by Mr. E. D. Self, one from an exposure near the Vegonia claim and the other from a quarry operated for flux at the north side of the laccolithic valley and in the surrounding rim. Both were unaltered blue limestone, resembling very much the usual Cambro-Silurian variety so abundant in the Great Valley of the eastern United States. A third sample was taken of a white marble, from the east side of the valley on Armadillos Hill. It came from a large mass of limestone, which had been included in the laccolith, and changed to a beautiful, saccharoidal marble.

	Vegonia	Furnace Quarry	Marble
	Per Cent	Per Cent	Per Cent
Insoluble,	5 04	4.31	9.55
Fe_2O_3, Al_2O_3,	0 35	0 95	1 28
$CaCO_3$,	94.55	93 83	88.92
$MgCO_3$,	0.58	1 29	0.91
Total,	100 52	100.38	100.66

These analyses indicate a limestone fairly pure, so far as insoluble silica or silicates go, and also low in magnesia. It may be queried whether the analyses are representative of the general rock of the section, where uninfluenced by the eruptives. Broadly speaking, it seems to me that this is probably not far from the truth. There are some beds with chert observed in the field which would run higher in silica, but these are very minor factors in the total. There may be more argillaceous beds, yet any, which are markedly shaly, failed to impress themselves upon us, the section presenting a rather strikingly uniform series of limestones. The analysis of marble shows a higher percentage, and it is possible that all of it was indigenous in the original unaltered limestone. This sample came from the specimen holding the still recognizable *lamellibranch* fossil, a type of shell, favoring muddy bottoms. We may therefore be prepared to admit in some parts of the limestone section, even as much as 10 per cent. of insolubles. Still, as the sample showed re-crystallization to marble, and as it gave gelatinous silica and probably therefore contained wollastonite, it may also be true that some silica had been introduced. At this point, however, it is the purpose to state facts rather than draw conclusions, and further discussion is postponed to a later page.

The simplest contact-effect, which has been noted, is the development of little bundles of tremolite in a limestone which has scarcely lost its blue color. The specimen was found on the southwestern edge of the laccolith near the Sante Rita trail. For the production of the tremolite it would not seem necessary to assume the introduction of silica from outside, but rather the re-crystallization of what was probably already in the limestone, under the influence of heat, or hot waters from the eruptive.

The next effect is to change the blue limestone into white marble. This change is the rule, with or without the additional production of garnet or other minerals. Sometimes the change to marble appears to be the only result brought about by the eruptive. The marble is of the usual variety. It has no associated minerals prominently developed and has been produced by the re-crystallization of fairly pure calcium carbonate with slight admixture of magnesium carbonate. In one interesting case, observed on the eastern side of the valley and already referred to, a fairly well preserved *Exogyra* was still recognizable in the marble.

The most important and extensive contact-effect is the alteration of the limestone to garnet and other lime-silicates. Many of the hand-specimens, which appear to the eye to be only brown garnet, are found to be more complex under the microscope. The production of the lime-silicates has taken place on a very large scale. Fig. 2 exhibits 65 different exposures. The focus of change is on the hill called Remedios, the summit of which is the mass of magnetite called the Piedra Iman or lodestone. The contact-zones are also extensive in Reina hill, and in a general course from the Santo Domingo claim through the Bretana and the San Mauricio toward and to the Vegonia. Around the rim, however, although not absolutely lacking, they are much less common.

The extent of the change varies from scattered nodules of garnet in limestone up to belts and masses many feet across. In most cases they lie along the borders of the limestone and porphyry, but there are occurrences with no visible limestone near, and then the masses of silicates seem to have resulted from the complete alteration of included blocks, torn off by the eruptive.

The garnet and its associated silicates are occasionally in banded or streaked formation, but more commonly they are quite massive. Small vugs or cavities with crystals exhibiting the rhombic dodecahedron are not uncommon. In larger cavities well-developed octahedral crystals of pyrite also appear, and all through the cavities and along cracks in the garnet, as well as included in its substance, chalcopyrite and pyrite manifest themselves. Some calcite is also occasionally visible in the garnet-zones and, as will be later noted, in two or three places considerable bodies of magnetite have been met, seamed in every direction with chalcopyrite and pyrite. After this general statement the more detailed discussion of the chemistry and mineralogy may be taken up in connection with the individual minerals.

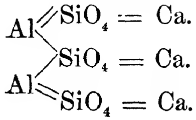
The simplest change in the alteration of the limestone to silicates is the production of wollastonite, CaO,SiO_2 (CaO, 48.3; SiO_2,51.7), by the replacement of the CO_2 of the limestone with SiO_2. This mineral has only been noted in the microscopic way. It shows an aggregate of brightly polarizing grains, many of which have a well-marked cleavage with parallel extinctions. In many cases the mineral lacks the elongated, fibrous or prismatic character of the usual wollastonite, but the optical and physical properties indicate its identity.

The next change, which involves the fewest chemical re-arrangements, is the production of diopside, the double bisilicate of lime and magnesia, CaO,SiO_2, MgO,SiO_2 (CaO, 25.9; MgO, 18.5; SiO_2, 55.6), which differs chemically from the wollastonite only on the fact that some magnesia is present with the lime. The replacement of CO_2 with SiO_2 is the only change involved. The reaction is the same as in the case of the tremolite, which has essentially the same chemical composition, but the latter was found in the blue limestone, while the diopside has only been observed in the zones of silicates. One slide revealed it in association with garnet and calcite. It formed irregular, brightly polarizing, almost colorless grains with characteristic optical properties. The low percentage of magnesia, both in the limestone and in the eruptive, has militated against its extensive production, garnet which requires no magnesia taking natural precedence.

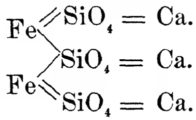
The most widespread and characteristic mineral of the con-

tact-zones from limestone is garnet. Garnet is, however, rather a name for a group than for a single species. The group consists of orthosilicates involving three molecules of H_4SiO_4 and having twelve bonds of affinity which are satisfied by three protoxides, such as CaO and FeO; and by one sesquioxide, such as Al_2O_3 or Fe_2O_3. By combinations of these, several distinct garnets can be made. Thus, $3CaO, Al_2O_3, 3SiO_2$ is grossularite,

Grossularite



Andradite.



the one which has been usually considered to be present in the zones. The fact that the garnets are light brown or pale green has given rise to this impression in the absence of chemical analysis, and upon the basis of the grossularite molecule the inferences about the constitution of the original limestone and development of the zones have usually been reached. Some doubt, however, arose in my mind regarding the correctness of this view, and a massive variety was selected for analysis. It was a pale reddish-brown in color. The results obtained, including the molecular ratios, are as follows.

	Per Cent.	Molecular Ratios
SiO_2, .	37.15	619
Al_2O_3,	6.98	69
Fe_2O_3,	19.40	120
CaO,	32.44	576
$CaCO_3$, .	4 20	
Soluble Al_2O_3, Fe_2O_3,	0 43	
Total,	100 60	

It was found on trial that the sample contained some calcite. It was therefore treated with very dilute hydrochloric acid, and from the solution enough lime was obtained to make 4.20 $CaCO_3$. The solution also yielded 0.43 Al_2O_3, Fe_2O_3, with perhaps a little SiO_2; the total was so small that no attempt to separate the constituents was made. No visible magnesia could be precipitated. It is possible that a little manganese was also present in the sample. It was not specially sought.

If we recast the above analysis so as to determine the rela-

tive amounts of the grossularite and andradite molecules, the results are as follows, using respectively the molecular ratios of alumina and ferric iron as the basis.

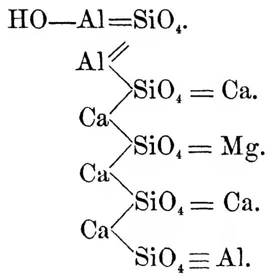
Grossularite			Andradite		
$3CaO$, . . .	207	11.60	$3CaO$, .	360	20.10
Al_2O_3,	69	6.98	Fe_2O_3, .	120	19.40
$3SiO_2$, . .	207	12.42	$3SiO_2$, . .	360	21.60
		31 00			61 10

There are not sufficient molecules of the alumina and ferric iron to care for all the silica and lime. The excess of the former is 619—(207 + 360) = 52, corresponding to 3.12 per cent. This would lead one to infer the presence of a little quartz in the sample, or else that in the garnet there was some diopside or wollastonite, both of which contain more silica than does garnet. Yet in any event the amount does not seriously affect the result. The lime is as follows, 576—(207 + 360) = 9, corresponding to 0.5 per cent. This may be due to the supposed diopside or wollastonite as just stated, or perhaps to error in the analysis. It also is not a serious factor. The chief result of importance, even admitting slight errors in determinations and assumptions, is to establish the relative amounts of the grossularite and andradite molecules. These are to each other as 31 to 61.1, or in percentages—grossularite, 33.7; andradite, 66.3.

The lime-iron garnet must therefore be esteemed of very great importance in the chemistry of the production of the zones, and theoretical discussions based on the grossularite molecule are open to objection to this extent. The importance of the whole matter lies in its bearing upon the question of the production of the garnet, whether by re-crystallization of an impure limestone or by contributions of silica, alumina and iron from the eruptive to a fairly pure limestone. This question will be taken up later. It may be remarked, however, that Waldemar Lindgren[4] also records the presence of the andradite molecule in large amounts in the zones at Morenci, Ariz., although the analyses have not yet been published.

[4] The Genesis of the Copper-Deposits of Clifton-Morenci, Arizona, *Trans.*, xxxv., 511–550

In association with the garnet is also found vesuvianite, a still more complicated compound, regarding whose exact formula there has been some difference of opinion. Writing it as it is given by F. W. Clarke,[5] it is $HCa_5,MgAl_3,Si_5O_{21}$, or if we expand it into a graphic form, which always helps toward a clear understanding, the following is obtained:—



The vesuvianite, as compared with the other minerals, only involves the addition to the limestone of the same silica, alumina and ferric oxide, together with hydroxyl or hydrogen; and both of the last named could easily be supplied by steam, conceivably dissociated under the pressures and temperatures attendant on igneous intrusion. The vesuvianite has been observed in one rare instance extending out as a small vein, 1 in. wide by 4 in. long, into the limestone, as if it had been formed on either side of a small crack by the introduction of the elements needed to change over the neighboring limestone. In the general mass of the contact-rock the microscopic examination has not indicated that it is frequent.

Of the other silicates, epidote, zoisite, biotite, albite, anorthite, etc., which are sometimes met in limestone-contacts, no occurrences have been noted.

Magnetite is a contact-mineral locally developed in irregular masses, which are of very considerable size. On the borders there are intermingled garnet and diopside, and throughout the magnetite are abundant veinlets of chalcopyrite and pyrite, but sections of the magnetite exhibit practically no transparent minerals. One prominent outcrop gave the name Piedra Iman or loadstone to the summit of Remedios hill. A large mass has been opened in the Santa Elena claim.

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[5] *Bulletin No* 125, U. S. Geological Survey, p. 25.

The magnetite must have been introduced in the same way as have the silica and alumina which have developed the silicates. The iron oxide has probably replaced the limestone and has thus formed local contact-masses different from the usual type. So far as the available evidence goes, the introduction of the magnetite has followed the garnet and diopside and has preceded much of the chalcopyrite and pyrite, since all manner of crevices in it are filled with veinlets of the latter.

In small pockety masses throughout the garnet and other silicates, calcite is occasionally seen. It may be either residual limestone not changed over into silicates, or it may be calcite of secondary introduction

Molybdenite has also been found by Mr. E. D. Self to be quite abundant in some of the workings opened since my visit. Thus in the Santa Elena adit, assays covering a considerable distance yielded from 0.5 to 1 per cent. of MoS_2. In the Santo Domingo shaft, Mr. Self has observed it, apparently in a garnet-zone that contained also vesuvianite. The occurrence of molybdenite at San Jose corresponds with Mr. Lindgren's observations at Morenci. The home of molybdenite is in the pegmatite-dikes, and it is interesting and suggestive to find it also in the zones, which must likewise be ascribed to expiring igneous activities.

The most important copper-mineral is chalcopyrite, quite invariably in association with pyrite. The two must have come in together. They appear not only as inclusions in the silicates, but also as veinlets and as coatings in cavities. They cover at times the well-developed crystals of garnet so as to mold around them like a paste The sulphides may themselves form large masses analogous to the magnetite and thus yield the best stopes of ore.

The usual oxidized compounds, malachite, chrysocolla and, less often, cuprite, may be seen. The mine-waters from the Santo Domingo shaft yield appreciable amounts of dissolved copper.

Since my visit, narrow veinlets of sulphide-ore rich in gold have been discovered in the porphyry and far from known limestone or garnet-zones, as observed by Mr. Self. These occurrences suggest parallels with Morenci.

IV. Genetic Conclusions.

Having the comprehensive statement of the minerals and their relations to the contact-zones before us, we may consider the possible, as well as the most reasonable, methods whereby they could have been produced. As incontrovertible we may establish at the outset the following premises.

1. The garnet-zones have been produced by the action of the diorite-porphyry upon the limestone.

2. The garnet-zones are irregular in distribution and in size. They are sometimes very thick and, again, white marble is alone developed next the eruptive.

3. The chemical compositions of the active agent, the diorite-porphyry, and of the raw material, the limestone, are as follows. Some, though probably not great, variation is admissible for each. To these are added the theoretical analyses of andradite and of grossularite, the most abundant molecules in the zones.

Diorite-Porphyry	Per Cent	Limestone	Per Cent
SiO_2,	62.31	Insol.,	4 to 5
Al_2O_3,	18 63	Al_2O_2,Fe_2O_3,	0.5 to 1 2
Fe_2O_3,	2 38		
FeO,	1 33	$CaCO_3$,	93 to 94
MgO,	0.60	$MgCo_3$,	0 5 to 1 2
CaO,	5 91		
Na_2O,	4.97		
K_2O,	3.52		
P_2O_5,	0.07		
H_2O,	0 23		
Total,	99.95		

Andradite	Per Cent
SiO_2,	40.0
Al_2O_3,	22.7
CaO,	37.3
Total,	100 0

Grossularite	Per Cent
SiO_2,	35.4
Fe_2O_3,	31 5
CaO,	33.1
Total,	100 0

1. *The Re-Crystallization Process.*

We may first raise the question,—whether it is conceivable that the garnet has been produced from the limestone alone. That is, are we justified in believing that the limestone was sufficiently siliceous and argillaceous, where we now find the zones, to have yielded the garnet and the other silicates without contributions from the eruptive? The belief that contact-zones are formed in this way is rather widespread and is based partly on general considerations and partly on the following specific cases:[6]

[6] For a general review of views upon this question with citations of authorities, see W. Lindgren, The Genesis of the Copper-Deposits of Clifton-Morenci, Arizona, *Trans.*, xxxv., 519–524.

1. In studying the contact-effects produced by the famous Shap granite of Westmoreland, England, upon amygdaloidal and altered basaltic rocks which it crosses, Alfred Harker concluded that the contact-minerals produced from the amygdaloidal fillings did not involve new contributions from the granite or the migration of the old materials farther than $\frac{1}{20}$ of an inch.[7]

2. Great bodies of favorable eruptive rocks, such as granite, sometimes break across thick sections of sedimentary rocks of all sorts, perhaps miles in extent, and yet produce extremely variable effects. Thus Dr. Joseph Barrell has described a case in the Elkhorn district, Montana. A mass of granitic rock has cut a thick sedimentary series. It has produced but slight changes where it penetrated pure limestones, the new minerals scarcely extending 5 ft. from the contact; whereas, where it cut the Starmount limestone, recognized to be siliceous and argillaceous, it has changed the latter to a mass of lime-silicates and feldspars for a quarter of a mile from the eruptive. The average composition of the contact-zone is grossularite, 60; diopside, 25; wollastonite, 15; total, 100 per cent.

When referred back to an original limestone which would yield this mixture, Dr. Barrell[8] found, by recasting the mineralogy, that it must have contained quartz, 21.3; kaolinite, 25.0; calcite, 46.6; magnesite, 7.1; total, 100 per cent.

The magnesite molecule was of course combined with the calcite in dolomite. If we express the above in percentages of oxides, they will be, SiO_2, 32.9; Al_2O_3, 9.9; CaO, 26.1; MgO, 3.38; CO_2, 24.22; H_2O, 3.5; total, 100 per cent.

Dr. Barrell does not give any analyses of the Starmount limestone, but from field-observation he apparently esteemed it to be sufficiently siliceous and aluminous to yield the lime-silicates. On the other hand, on p. 291 of the paper in the *American Journal of Science*, he says, regarding the contact-zones from this limestone, that

"The rocks are dense and even-grained and without cracklings or infiltrations of quartz or calcite. The thin sedimentary banding is still preserved with the

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[7] *Quarterly Journal of the Geological Society*, xlix., part iii, 368, 369 (Aug., 1893).

[8] Physical Effects of Contact-Metamorphism, *American Journal of Science*, April, 1902, 291–292. See also Weed and Barrell, 22*d Annual Report*, U. S. Geological Survey, Part II., 399–549.

same lenticular, somewhat concretionary, structure observed at a distance from the igneous intrusions, and the adjacent layers, where of different mineral composition, are sharply separated from each other. Certain strata may show a few per cent. of calcite, but this is distributed in a manner which indicates that it is not a secondary addition, but on the contrary is due to those beds containing originally more calcium carbonate than could combine under metamorphic action with the quartz and kaolin present These features sharply separate the mass of the Starmount strata from certain beds which, owing to special conditions, do show infiltrations, as indicated by nuclei of quartz with fluorite and ore-grains."

In the third following paragraph (p. 292) he says:

"In the process of metamorphism this mass of strata (i e the Starmount) has lost approximately 28 per cent. of its weight, and 45 per cent. of its volume, from 70 to 90 times its volume of water and 320 volumes of carbonic dioxide, the gases being measured at 0° C. and 760 mm."

While it is the purpose at this point to state, with all possible emphasis, the points favorable to the re-crystallization of the material *in situ;* and while the perfect preservation of the old bedding with the introduction of new material may not be without difficulties, yet one cannot but remark, in passing, that the production of a rock "dense and even-grained and without cracklings," while at the same time losing "28 per cent. of its weight and 45 per cent. of its volume," is also fraught with other, perhaps greater, difficulties.

3. We sometimes find the zones of silicates, even in the same great stratum of limestone, following certain beds for a long distance away from the eruptive, while the beds on either side are white marble. The zones may even be greatly contorted and yet persistent. Dr. W. L. Austin has called my attention to a very striking illustration of these relations at Sacrificio mountain, Nombre de Dios, Durango, Mexico, of which a photograph is reproduced in Fig. 3, in which the zones are wollastonite. It would seem from this as if the siliceous beds yielded wollastonite and the neighboring, calcareous beds marble. No doubt these cases strongly favor re-crystallization *in situ.* The interesting zones at San Pedro, N. M., described by Messrs. Yung and McCaffery,[9] might also be considered to give additional support, when one studies the map and section, showing

[9] The Ore-Deposits of the San Pedro District, N. M, *Trans.*, xxxiii., 350 (1903).

the occurrence of both shaly and purer limestones. But they also remark (p. 355), that "the limestone left in contact with the garnet is always more siliceous than the limestone further removed from the ore-body" and, as will be brought out for San Jose, it does not seem probable, when the varying occurrences of the garnet-rock are properly considered, that the eruptive, when the garnets were developed, should happen always to be next to a specially siliceous portion.

Before we turn to the considerations positively favoring the contribution of material from the eruptive it may be remarked

FIG. 3.—ZONES OF WOLLASTONITE IN MARBLE, NOMBRE DE DIOS, DURANGO, MEX.

(From a photograph by W. L. Austin.)

that wide experience has demonstrated that the development of contact-effects is, as a rule, irregular, showing great strength at certain places and a well-nigh incomprehensible failure at other, apparently equally favorable points. We have best accounted for these relations by believing that the contact-effects are the results of the emission of gases, vapors and liquids, especially water in its several physical states, and that these were freely afforded at certain points and failed at others. There is great reason for believing that this is true. Those eruptives, moreover, which fail to produce contact-effects, are probably lack-

ing in the dissolved gases, etc., and are cases of relatively dry fusion.[10]

Admitting the addition of material from the eruptive, two possible methods are to be considered. A contact-zone may be due to the fusion of the wall-rock into the eruptive and its consequent absorption, yielding a product of intermediate composition; or it may be due to the emission of gases, vapors and heated liquids in the process generally described as hydrothermal. We may consider the first method at the outset.

2. *The Absorption-Process.*

The garnet-zones at San Jose are in a general way intermediate in composition between the eruptive and the limestone, but so far as observation goes, they lack feldspar entirely and this mineral ought not to fail if absorption took place. Moreover, the irregularity of distribution; the sharp contacts; the obvious effects of chill on the eruptive, as shown by the changes in texture and the occasional presence of scattered garnets in predominating limestone,—all militate against its application. Artificial experiments, moreover, in the production of garnets of the grossularite type has shown that, when their component materials are fused together, or when they themselves are melted, the resulting product is anorthite, melilite and pyroxene. Therefore, while absorption-phenomena have been with good reason called into play to account for some contact-phenomena, as, for instance, the curious rocks at Pigeon Bay, Minn., described by W. S. Bayley;[11] yet in the typical garnet-zones they have small claims to confidence.

3. *The Process by Contributions from the Eruptive.*

In the cooling of the eruptive there must have been a stage when the emissions were of necessity gaseous, and a later stage when they were liquids, and still a third stage when meteoric waters, if such could penetrate to the still-heated eruptive, must have been set in circulation by it at temperatures below the boiling-point, else it is difficult to conceive of water reaching the heated eruptive against steam-pressure, except perhaps very locally and for a brief season.

[10] This subject is briefly summarized in Kemp's *Handbook of Rocks*, 3d Ed , Chapter IX.

[11] *Bulletin No.* 109, U. S. Geological Survey.

In his study of the Clifton district, Mr. Lindgren has attributed the garnets and other silicates to the stage of gaseous emissions, particularly of water-gas accompanied by silica and iron. This is quite reasonable and it may be that, at San Jose, the garnet-zones, the magnetite and the copper-ores were formed at this time. From the evidence in hand, however, there seems no reason to eliminate heated waters as also possible agents. The chief and most tangible interest centers around the question of the introduction of silica, iron and, perhaps, alumina from the eruptive.

That these three must have been added to the limestone in order to produce the zones of silicates, the chemical analyses of the unaltered rock and the field-observations make practically certain. Otherwise, we cannot easily understand how limestones, ranging from 4 to 5 per cent. of insolubles, attain from 40 to 50 per cent. of silica and alumina. Regarding the silica and the iron there is no special chemical difficulty, but the alumina is perhaps different. In the general weathering of rocks, such as granites, we usually consider the alumina as the stable oxide, and, assuming that it remains comparatively unaffected by the natural agents, we calculate back to original compositions. At the same time we have as a suggestive compound of aluminum, the fluoride, cryolite, a mineral easily soluble in sulphuric acid with the evolution of hydrofluoric acid. Its properties would suggest the inference that, at the temperatures and pressures prevailing during the cooling of a rather deep-seated intrusive rock, it may well happen that aluminum is far from being inert. When we compare its great abundance in the porphyry, from 18 to 19 per cent., with the 1 per cent. and less in the limestone analyzed, the former seems to be much the more probable source.

Again, if we are still favorably inclined to believe in an original siliceous and argillaceous composition of the limestone, and, recognizing the comparative rarity of this variety so far as observation goes, if we try to conceive of just this variety happening to be next the eruptive wherever we find the garnet-zones, widely distributed as they are, both vertically and horizontally; shading off as they occasionally do into pure white marble, without regard to original stratification; and in neighboring places abruptly failing in favor of the marble; we are

confronted with grave difficulties—much graver ones, in fact, than are presented by the assumption that the eruptive contributed the necessary materials.

Still again, if we recall the fact that the garnet-rock is, on the whole, a fairly dense and solid variety, which might be produced from limestone by new contributions of silica, alumina and iron, able to take the place of the eliminated carbon dioxide; whereas, the re-crystallization of an impure limestone requires the production of cavities, theoretically more than 40 per cent. of the original volume; we shall find, for the San Jose case, that the addition of new material involves fewer difficulties and is, in fact, the only reasonable explanation. The cavities, which are observable and which are filled in part by the sulphides, are probably due to the rearrangements brought about by the combination of the 4 or 5 per cent. of insolubles with the lime of the calcite, and the attendant loss of carbonic acid involved.

The bodies of magnetite were doubtless formed by direct replacement of the limestone with the iron oxides, and seem to indicate a local richness in iron for the emissions from the eruptive where they are found. There is slight, if any, reason to regard them as other than purely contact-products. One or two little pockets of specularite were observed, but this mineral does not exhibit the abundance shown elsewhere, as, for instance, in the zones at the Seven Devils, Idaho.

The introduction of the sulphides seems to have been, in largest part, one of the later phases of the contact-metamorphism, and to have followed the production of the silicates at least in part. We infer this from the relations described under the sulphides that, besides forming inclusions in the silicates, they mold around the garnets, and follow crevices in the magnetite. Where they constitute large masses they doubtless replaced the limestone, although in the midst of the contact-zones.

4. *Oxidized Ores.*

The production of the oxidized minerals has been favored, in at least one or two cases, by faults. It is possible to show the existence of the latter by the heaved condition of the tinguaite dikes, and, near the natural conduit thus afforded for the de-

scending meteoric waters, the formation of oxidized minerals has been recognizable.

As is often the experience with copper-ores in deposits of this type, a small amount of gold is shown by the assays. Other metals are practically lacking and the matte is very clean.

The Manufacture and Characteristics of Wrought-Iron.

BY JAMES P ROE, POTTSTOWN, PA

(Washington Meeting, May, 1905)

I. Introduction.

Those who deem the subject of this paper an old and superseded one may recall with advantage the words of the great proverb-maker, bidding us to seek the new in the ashes of the old.

The manufacture of wrought-iron began with the small hearth built upon an eminence, and relying on the wind for blast. Next came, either the hearth about 12 in. in diameter by 2 ft. in height, blown by a man operating two goat-skins for bellows, or, a hearth of greatly varying diameter and about 10 ft. high, depending for its blast upon natural draft. The former appeared in India, the latter in Burmah; and both were in operation until quite recently, though their origin is lost in prehistoric times.

The Catalan forge was the evolutionary descendant of the foregoing, and the parent of the *Blase-ofen*, which in turn led to the high bloomary or "Stuckofen," the father of the blast-furnace, as a producer of cast-iron.

The production of cast-iron checked the growth of the direct processes; and led to the introduction of various hearths, such as the Walloon, for low-silicon irons; and the South Wales process, combining the run-out fire with the finery, for higher-silicon irons. Some of these are still in operation in localities possessing the necessary raw materials; and their product is used for purposes requiring wrought-iron of exceptional quality, the supply of which is still smaller than the demand.

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We have to look back but a century and a quarter to see the introduction of the puddling-process by Henry Cort; a process which, reinforced by the iron-oxide bottoms and fettling of Hall, was not less revolutionary in character, and more revolutionary in effect, than any other single step in the metallurgy of iron.

Cort was the first to avoid contamination of the product through contact with the fuel, thus increasing the available fuel-supply, and permitting a limitless variety of forms for the furnace. In conjunction with Hall's improvements, his process was the first, and still remains the only one, which can furnish a good product from pig-irons relatively high in silicon, phosphorus and sulphur. Other processes can only take care of one, or at the most two, of the metalloids named. The vastly increased supply of iron-ore thus made available had much to do with the supremacy in the iron-manufacture so long held by Great Britain, while it promoted also the industrial progress of other nations.

The circumstance that pig-irons high in phosphorus and sulphur may be used in puddling has more than an immediate commercial significance. In view of the immense and ever-increasing consumption of iron, there must be a limit to the purer ores and fuels available; and a process in which not only phosphorus and sulphur can be eliminated to any desired extent, but the finished product of which may, if wished, retain four times as much phosphorus as good steel, and yet be a thoroughly reliable material for use, is certain to play a part in the fate of nations.

The puddling-process, as carried out by Cort, and later known as "dry puddling," was effected upon a sand bottom and was open to the objections: (1) that the oxidation of the metalloids was effected by atmospheric action, resulting in high loss; (2) that the volume of cinder, as a receptacle for oxidized impurities, was small, and hence the range in character of pig-iron available was limited; and (3) that, as a consequence, various kinds of so-called "physic" were employed, resulting in an uncertain product.

The puddling process of to-day, known as the "pig-boiling process," and invented about 1830 by Joseph Hall, consists in the use of relatively infusible oxides of iron for the bottom- and

side-fettling of the hearth. Its results are smaller loss of metal, greater output of more certain character, the possibility of using gray pig, and the furnishing of the "physic" that had so long been sought.

The process is both simple and beautiful. Simple, in that the fettling or "fix" forms a reservoir of relatively pure oxide of iron which is automatically drawn upon by the cinder of the bath for correction: that is, the higher the silica of the bath, the greater its draft upon the relatively basic sides and bottom, to produce a final cinder, low and constant in silica, which is the factor controlling the phosphorus and sulphur of the product from a given grade of pig-iron;—beautiful, because the reactions, or their immediate effects, and the crystallization, are all plainly visible and well-defined.

The process consists, essentially, in the removal from molten pig-iron of nearly all its carbon and silicon, and most of its phosphorus and sulphur, by agitation in the presence of a suitable cinder, and gases of the right composition and temperature; and, finally, by crystallization, due to the greater infusibility of the iron as the metalloids are oxidized and removed.

It demands of the puddler a reasonable degree of skill, and a kind of labor which, though healthy, is very severe. The necessity of such labor has long been recognized as the great practical difficulty and expense of the process; and numberless mechanical devices have been proposed for its diminution, but, thus far, without any marked degree of success.

II. Mechanical Puddling.

The attempts at mechanical puddling may be summarized in four general classes.

1. The use of hollow rabbles operated by hand, through which air or steam (sometimes both) were forced into the bath. These involved complications, a necessarily high loss of iron, and little, if any, saving of labor.

2. Stationary furnaces, such as Clough's mechanical puddler, resembling in general outline the ordinary puddling-furnace, with rabbles operated mechanically. The objections to this type are its complication, and the fact that it is applicable only to the puddling-period proper, and the rabbles are in the way during fettling, charging, balling and drawing. In fact,

it cannot satisfy the proper requirements for a successful mechanical device, which demands constant motion, or a constant cycle of motions, either of which, in turn, calls for uniform shape and conditions; whereas, in a puddling-furnace, these factors are ever varying.

3. Revolving furnaces, represented by two distinct types—the Danks and the Pernot, and their respective modifications.

a. The Danks furnace consists of a stationary fire-chamber, a cylindrical hearth revolving about a horizontal axis, and a removable flue-section, giving access to the hearth for charging and drawing. The advantages of this furnace, which came so near success as to mislead many acute experts, consisted in reducing the labor of puddling and balling; thoroughly agitating the heat; and working on a hot bottom. Its disadvantages were: the excessive time and labor expended in fettling; the difficulty of drawing the heat; the troubles connected with the lining of the revolving portion alternately forming the roof and the hearth; and, worst of all, the balling of the heat before all the iron was "ready," which produced blisters. The product is only available as open-hearth resmelting-stock, for which purpose it is used, in small quantities, to-day.

b. The Pernot furnace has a hearth like a frying-pan, which revolves round an axis slightly inclined from the vertical. This slight inclination failed to impart sufficient agitation to the bath, and collected the crystals into a ball. Hence the rabble and paddle were resorted to, which, in conjunction with the same means of fettling and drawing, as in the ordinary puddling-furnace, put the Pernot upon the same plane, plus some complications.

4. The oscillating furnace, operating on either a longitudinal or transverse axis, which holds the germ of successful mechanical puddling. Some furnaces of this type, however, were hampered by too narrow mechanical limitations; others were too complicated; and all of them have hitherto proved incapable of accomplishing the whole of the process.

The advances in puddling, thus sketched, have been disappointing, and not at all in keeping with the progress achieved in blast-furnace practice and steel-making. This may be explained in part by the vast technical knowledge applied in recent years to pig-iron and steel, leaving the puddling-mills largely

to the "practical" men, who have worked their way from puddlers to foremen, and possibly to superintendents, without becoming emancipated from the traditions to which they were born.

III. Reactions of the Puddling Process.

As already remarked, the puddling-process permits the use of irons of greatly varying composition. My experience covers irons containing as much as 3 per cent. of silicon and of phosphorus, 2.5 per cent. of manganese, and 0.35 per cent. of sulphur, though, of course, not all in the same pig-iron. In all these cases, iron was produced that would weld freely, and showed no cold- or red-short tendency. It is not my intention to convey the impression that such extreme irons are desirable. On the contrary, they are costly in time, labor and iron-loss. For rapid work, good yield, and fitness for ordinary uses, a desirable composition would be about 1 per cent. of silicon, a somewhat smaller percentage of phosphorus, 0.1 per cent. of sulphur and 0.5 per cent. of manganese. For special grades, it is necessary to select the pig in each particular case.

The various iron oxides, charged as fettling, flux and oxidizing agents, should be characterized, in the order named, by infusibility, fusibility and the ability to be readily reduced, for the part they respectively play in the operation. The flux, as the material directly forming the cinder, must be present in sufficient quantity to receive the oxidized metalloids, and low enough in silicon to retain them as the temperature of the bath increases. This cinder is the vehicle for oxygen, whether supplied by roll-scale, ore, or the oxidizing gases of the furnace; it protects the puddled mass from undue oxidation by the gases; and, finally, it forms the welding-cinder. Its composition is changed during the process by additions; by reactions upon the fettling and the bottom; and by the condition of the fire and position of the damper.

The control of the volume of cinder, in the various stages of puddling, up to the finished product, may be mentioned here. Throughout all these stages, it is primarily controlled by its composition as effecting its fusibility. In the ball when drawn, it is controlled largely by temperature at the time of going on high-boil and at the time of drawing; this temperature, at both periods, being chiefly governed by the damper. In the shingled

ball, it is controlled by the amount of work or pressure; the cinder being generally smaller in amount when a hammer, than when a squeezer, is used. In the puddle-bar, and in the finished product, it is dependent upon the reduction in area and the rapidity of this reduction. These conditions put the process thoroughly under the control of the operator.

High cinder-content is desirable for free welding, for such

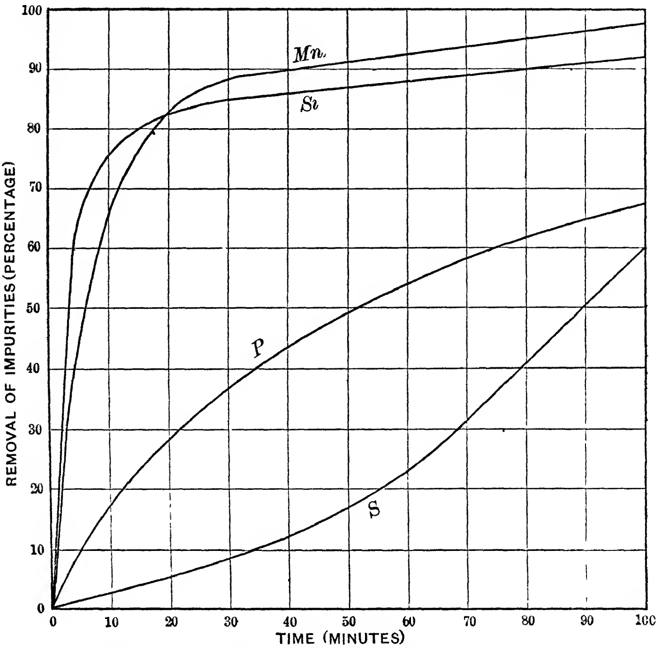

Fig. 1.—Removal of Impurities from Iron During the Puddling-Process.

purposes as pipe-making, etc.; and low cinder-content, when the product is to be subjected to severe physical strain.

The order and proportions of the oxidation of the principal metalloids are shown in Fig. 1.

The object of agitation, which is ordinarily accomplished by the rabble, is, to produce as uniform conditions as possible throughout the bath; to bring into intimate contact the cinder and iron; and to prevent as far as possible the settling of the iron, in a partly refined condition, on the relatively cold bottom, which would cause it to become too cold on the under

side. This occurs in a measure during the "drop," (particularly in large furnaces), and necessitates "turning."

Small heats, such as are still worked at Low Moor, England, are best adapted for uniformity of product; since the workman has not the physical strength and endurance to agitate the larger baths efficiently, though he obtains material assistance from a good "high-boil." Another disadvantage in large furnaces is the necessity of starting to draw "young," since otherwise the later balls are subject to severe loss. The irregularities thus produced are, however, largely overcome by the subsequent treatment of piling and reheating. Piling operates as a fairly efficient mixing by the natural law of chances; and reheating helps, by maintaining the iron at a temperature, and for a period, which permit both the oxidation of the carbon of the "young" iron and the reduction of some of the cinder present. Hence, the small pieces of which an iron pile is formed are desirable under existing methods of producing puddled iron. But piling has also its disadvantages, in the production of laminations, due to carelessness, or lack of means or skill, and in the high cost of handling loose piles.

IV. The Structure of Puddled Iron.

Puddled iron "comes to nature" or crystallizes at a relatively low temperature—i.e., low compared to steel—due to the increased infusibility of the iron as the carbon is eliminated. Each grain or crystal is surrounded by an envelope of cinder; which, when the clusters are dense, fills the intervening spaces. The greater part of this cinder is then hammered or squeezed out, and the succeeding operation of rolling elongates the crystals into what are commonly known as fibers, each fiber existing in a matrix of cinder. This fibrous formation in a matrix of ferrous silicate is the controlling characteristic of wrought-iron, and the source alike of its virtues and its faults. The fibrous structure can be distinctly seen under the microscope at various powers, and often with the naked eye. It is perhaps more correctly described by Prof. Howe, who says: "I understand that this 'sort of fiber' is more apparent than real, the grains themselves being equi-axed, yet separated into quasi fibers by layers of slag. . . ."[1] Admitting the correctness of

[1] *The Metallurgy of Steel*, by Henry M. Howe, p. 193

this remark, each series of crystals forms an integral structure, which has to be ruptured separately, producing, in every-day practice, results analogous to those we would look for in a true fiber.

Many instances of the arrest of fracture by the fiber occur in the experience of most engineers with shafts, bolts, chain-hooks, etc. An illustration recently came under my observation: about two years ago, a shear cam-shaft, 9 in. in diameter by 48 in. between journals, was bent about 0.5 in. at one side of one of the two cams, producing a crack about 2 in. deep and open almost an eighth of an inch. The lateral movement of the large spur-wheel, due to the bend, was carefully noted, and measured at frequent intervals to learn whether the fracture was extending. As it did not extend, and no convenient opportunity offered for straightening the shaft, it ran till July of last year, when it was taken out, straightened and replaced. It is doing good work, and running true to-day. Had it been steel, it would have been necessary to take it out at once, and, after straightening, to anneal it; even then, a greater risk would have been run than with wrought-iron.

Drive-pipes for wells furnish another illustration. Wrought-iron withstands the shock of driving at the threads, whereas steel breaks off at the root of the threads.

A blast-furnace plant of two stacks had an experience bearing upon this question. One stack was erected about 30 years ago, with a shell of wrought-iron plates; the other, about 4 years ago, with a shell of basic open-hearth steel plates. Both were evidently subjected to the same character of strains, and in approximately the same position. The wrought-iron shell bulged out under strain, but did not crack; while the steel shell suffered a vertical rupture extending about 20 ft., and not following, to any marked degree, the lines of the riveted joints.

Physical tests of steel, made in the laboratory, on an 8- or 10-in. section give results which superficially appear to be superior to those of wrought-iron, particularly in the feature of elongation. But when studied with greater care the elongation is seen to be largely concentrated, and not so uniformly distributed throughout its length as is that of iron.

This tendency to concentrated elongation in steel, and to more widely distributed elongation in wrought-iron, is shown

in their respective tests, in full-sized sections, of eye-bars for bridges; the specified elongation being the same for iron and steel in a length of 10 feet. The following are results of such tests:

	Elastic Limit	Ultimate Strength	Elongation, Per Cent		Reduction of Area
	Lb. per Sq In.	Lb per Sq In	In 12 In	In 18 Ft	Per Cent
Iron..	31,550	48,810	23	15.22	28.30
Steel.	33,150	59,260	39	14.40	51.50

There is greater general confidence in welded articles made of iron than of steel, which is well-founded: the cinder present in iron, and its low carbon-content, naturally facilitate welding. This receives further confirmation from the fact, that as the carbon is increased in steel, the uncertainty of a good weld becomes greater.

V. Resistance to Oxidation.

That wrought-iron resists oxidation better than steel is becoming the general opinion of those who have studied the question under actual working-conditions. The difference is naturally more apparent in thin objects, such as corrugated roof-sheeting, tin-plate for roofing and the like; but its influence is the same regardless of mass. The difference in the life of light sections is about as five to one in favor of puddled iron.

The explanation of this resistance to oxidation is two-fold.

1. The cinder, a ferrous silicate, enveloping each fiber, is much attenuated by rolling, and in this condition is elastic. A piece of iron fresh from the rolls is covered with relatively thick scale, which will readily crack off to a large extent, exposing a surface of iron fibers with the intervening cinder. These fibers oxidize somewhat rapidly, leaving a finely corrugated surface of cinder, which resists further atmospheric action, as may be seen in heaps of scoria from old hearths, believed to date from before the Christian era. Being elastic, it resists for considerable, though varying, periods; but eventually it cracks off under vibration, expansion and contraction, or mechanical wear. The cycle is then repeated and so on.

2. Puddled iron is a mechanical combination of two substances, iron and cinder, which offer different resistances to

such pressure as that of rolls or hammers. The result is a rough surface, which forms a more lasting bond with any protecting agent, such as tin or paint, than the smooth surface of steel, which does not aid in any way the adhesive qualities of the protecting agent.

In connection with the question of oxidation, I may instance the experience of a large tube-works, carrying a considerable stock of iron tubes, and accustomed to take from, and add to, the top of the stock-pile, without regard to the tubes in its lower part, knowing that these, when ultimately reached, would be found to be corroded uniformly over their whole surface, but could be re-rolled to a lighter gauge, producing perfect tubes. After beginning to make steel tubes, they followed the same practice; but these tubes were found, after re-rolling, to be pitted through, and therefore valueless.

I am indebted to Dr. Raymond, Secretary of the Institute, for the suggestion contained in the following communication:

"In preparing your paper for the press, I notice that you have omitted to mention, in connection with the question of the more rapid oxidation of soft steel, a chemical reason, namely, the presence of manganese in that metal. Many years ago, as consulting engineer of the firm of Cooper, Hewitt & Co., I approved the substitution of low-carbon steel for wrought-iron, for certain articles of manufacture The immediate result was complaint from both consumers and selling agents, that these articles rusted so soon as to look old even upon delivery. A careful investigation, conducted for the firm by the late Dr. T. M. Drown, located the source of this trouble in the manganese of the low steel, or "ingot-iron." In that particular case the rapid surface-corrosion probably did not affect the real usefulness of the articles. But it may easily be inferred that, when a coating of tin, zinc or paint is applied to a sheet of metal, a very slight extra liability to oxidation in that metal may set up a series of chemical and galvanic reactions of destructive character.

"I have had recent occasion to realize with surprise and consternation the imperative necessity of frequent repairs to roofs, pipes, etc., of tinned or galvanized iron My trusted mechanic declares that all his customers are similarly affected, and protests that he can no longer obtain anywhere materials of this class as durable as they used to be. He thinks that something is the matter with the processes of coating with tin or zinc; but I shrewdly suspect that the trouble lies in the manganese of the metal coated, and in the series of reactions which its easy oxidation initiates.

"It seems to me that the 'pitting' of steel, to which you refer, is directly due to manganese."

VI. Defects of Wrought-Iron.

Under this head, we have to consider transverse weakness, lower ultimate strength, laminations, and high labor-cost in production.

1. Transverse weakness is inherent, though less marked as the cinder-content is reduced.

2. Lower ultimate strength and elastic limit, demanding (for the same factor of safety, and if the possible effects of the "pitting" of steel be ignored) a greater section for a given strain, is also an inherent weakness, so long as the product is made from built-up piles, requiring low carbon as an essential condition for good welding.

3. Laminations, due to imperfect welding, are commonly the result of inefficient machinery, or lack of skill. This defect also is inherently associated with the use of built-up piles, especially when these are made, wholly or in part, from scrap of miscellaneous character. I recall an instance, in which a lot of $1\frac{1}{8}$-in. "rounds" were ordered to be made for special bolts, from muck-bars only. While cutting them to length on the anvil, we noticed that, after superficial nicking, some pieces fell off, even without bending. Upon investigation, the so-called "iron" was found to include pieces of hard steel rail, fairly well defined in form, and surrounded by soft wrought-iron, presumedly "muck-bar," which peeled off with the freedom of a banana-skin; the exterior and the core not being welded together.

4. The high labor-cost of production is probably the principal cause which has checked, during recent years, the legitimate increase in the use of wrought-iron. It is constantly receiving greater emphasis, as the younger generation of workmen, with greater educational advantages, turns away from arduous manual toil, and particularly from the opprobrium attached to the term "puddler," as indicating a relatively servile and ignorant class. This stigma has existed from time immemorial in India, where the iron-worker is ranked in the lowest caste. The severity of the work, together with the inferior social status of the worker, have depopulated puddling-mills in this country and England, and caused, in certain districts, the abandonment of puddling.

With the exception of relative transverse weakness, all the above short-comings of wrought-iron are due to the method of manufacture, rather than to inherent qualities of product. Iron puddled in large masses by mechanical means, and rolled direct, as soft steel is, would give us fibrous structure; resist-

ance to oxidation; high tensile strength; low cost, and the absence of laminations. Such a material would cover the field now jointly held by puddled iron and soft steel, even to the possible use of the latter for rails.

VII. Conditions Essential to Successful Puddling.

The conditions necessary to produce such iron are: (1) a large unit of manufacture; (2) adequate mechanical means; (3) cinder of proper composition; (4) a flame of the right composition and temperature; (5) a relatively permanent furnace lining; (6) a relatively small loss of iron; (7) simplicity of means and method.

1 and 2. These two conditions are the chief factors (indeed, if we consider Bessemer steel alone, the only ones) in the low cost of steel-manufacture; and if they were introduced into the production of wrought-iron, they would have a like effect upon its cost. I will consider later the means of effecting this end.

3. As already shown, the right cinder for the puddling-process is largely produced from, and corrected by, the oxides forming the sides and bottom of the hearth. It is, however, evident that the purer oxides of iron are inert while in position, and only become active after absorption into the bath. Hence, when suitable oxides are introduced in the form of cinder, ore, and roll-scale, there is no need of drawing upon the bottom and sides, provided these latter are of such nature as to resist the chemical action of the cinder and the temperature of the gases.

4. The proper regulation of the flame is essentially a simple matter, presenting difficulty only when associated with a movable furnace.

5. The lining offers a somewhat complex problem, both metallurgically and mechanically. It must resist the chemical action of a complex cinder; the friction of the mass as the iron comes to nature; and a somewhat high temperature. Moreover, in a mechanical furnace, it must maintain its position throughout the movements of the furnace itself.

6. The minimum loss of iron is secured by the reduction of some of the iron-oxide additions, resulting in an actual gain of weight of the puddled mass, over the pig charged, in an ordinary puddling-furnace. This gain is exceeded by the final loss,

due to the delay in the period of balling and drawing. By reducing the period of drawing, as by discharging the whole mass in one piece, this loss may be avoided, and a possible net gain effected.

A mechanical puddler, erected at Pottstown, Pa., and fulfilling the conditions above stated, was described by the writer at a former meeting of the Institute.[2] To that description, the reader of the present paper is referred.

Repairing Partly Collapsed Cylindrical Furnaces.

BY JOHN P COSGRO, ROSSLAND, B C.

(Washington Meeting, May, 1905)

THE increasing use of internal furnace-boilers for power-plants at mines (doubtless due to the facility with which they may be installed by reason of their portability; the fact that they require no masonry setting, cast-iron fronts, buck-stays, etc., and practically no foundation; and the successful maintenance of their claim to equal and even superior economy, as compared with boilers of other types[1]) warrants this description of a method of remedying an injury which may occur, to such a furnace, even though it satisfies the requirements of the formula adopted by the U. S. Board of Supervising Inspectors of Steam Vessels.[2] I refer to the sagging and deformation which may result from overloading the boilers for a considerable period—say, several days. This is sometimes unavoidable under the exacting conditions of continuous day-and-night service, and (in spite of all rules and precautions) the occasional careless or unskillful work of attendants. Such a trouble is by no means unknown on shipboard, where this type of boiler is so largely employed.

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[2] Puddled Iron and Mechanical Means for its Production, Philadelphia Meeting, May, 1892, *Trans.*, xxxiii., 551

[1] Comparative Efficiency of Internally Fired and Externally Fired Boilers, by D. W. Robb, *Engineering Magazine*, April, 1904, pp 91–100

[2] This formula is $P = \frac{15000}{D} \times T$, in which T is the thickness of furnace in inches; P, working-pressure in pounds per sq. in; 15000, a constant; and D = mean diameter (least inside diameter, plus thickness of metal, plus 1.5 in.)

In the case here described, two Morrison suspension-furnaces, of half-inch steel, 14 ft. long and 45 in. in mean diameter, with "dry-back" boilers, were necessarily operated somewhat beyond their rated normal capacity for several months, while a third similar unit was in process of installation; and during this period, though the boilers were kept perfectly clean, heat seems to have been generated slightly faster than it was absorbed by the water in the boilers. The corrugations of this type of furnace have the form of a catenary, with 8-in. span and a versed sine of 1.5 in., and, as a result of the abnormal strain above described, the furnaces had partly collapsed, or dropped a total distance of $1\frac{3}{16}$ in. As would be expected, the greatest deformation was just back of the bridge-wall; and since external pressure always tends to increase greatly the least departure from a true cylindrical cross-section, forcing it to become more and more elliptical, and finally to collapse and fall, it was advisable to correct immediately the change already effected, by restoring the original form of the furnaces.

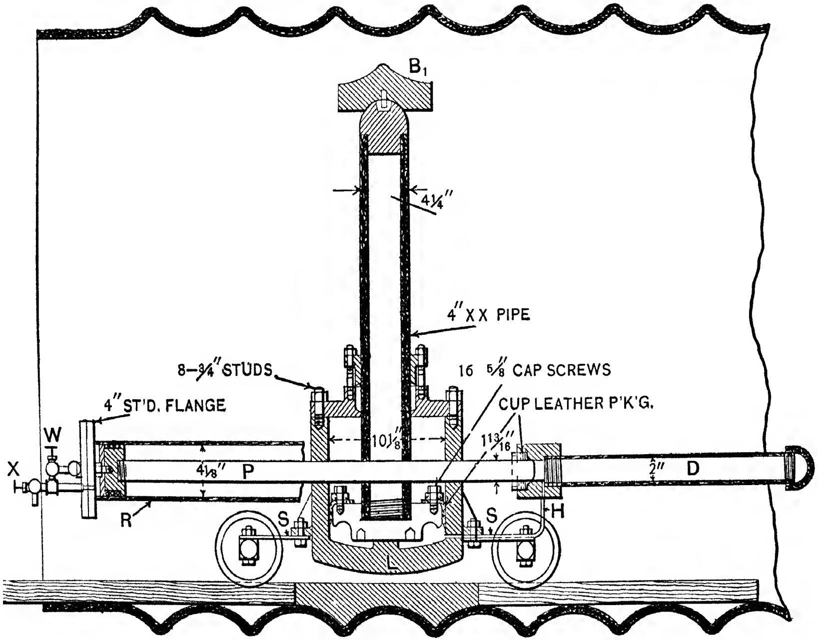
The method proposed by the Government boiler-inspector, namely, to heat the metal, and press it up into place with a ack-screw, was impracticable, because, when a half-inch steel shell is hot enough to be set with a jack-screw, it is altogether too hot for a man to work in.

The work was done successfully by means of a simple hydraulic press, designed for the purpose, of which Figs. 1 and 2 are cross-sections, Fig. 3 a right-line drawing prepared from a photograph, and Fig. 4 a sketch showing the general arrangement and method of operation.

A natural hydrostatic pressure of about 250 lb. per sq. in. was available from a tank on a hill several hundred feet above the boiler-house, through the pipe-line of the general fire- and water-service. Using this pressure direct, we obtained by means of the $10\frac{1}{8}$-in. lifting-cylinder, L, Fig. 1, a lifting-force of 10 tons at the pressure-head, B_1.

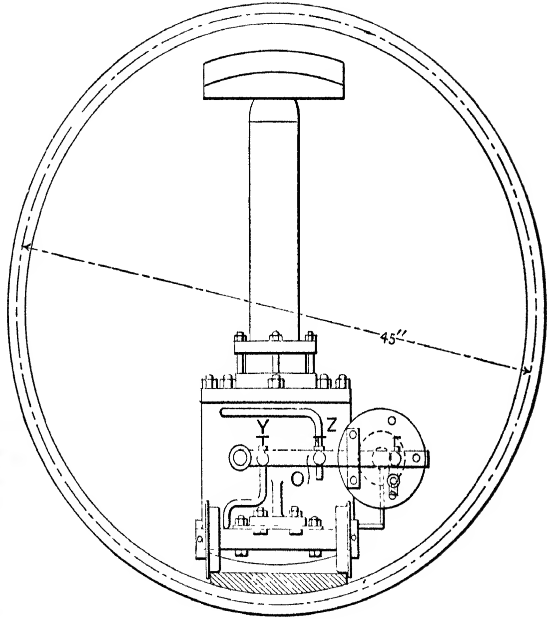
No data being obtainable as to the force necessary to press up the dropped crowns, it was seen that the required lifting-capacity must be largely a matter of judgment. At the time, it seemed to me unlikely that more than 20 or 30 tons would be needed; but, in view of other work then in contemplation,

Fig. 1.



LONGITUDINAL CROSS SECTION

Fig. 2.



TRANSVERSE CROSS SECTION

Hydraulic Press Designed for Repairing Partly Collapsed Cylindrical Furnaces.

a capacity of 50 tons was provided; all of which was, in fact, required in re-shaping the furnaces.

A flexible conduit, a piece of new 1-in. air-hose taken from stock, was connected from the pipe-line to the pressure-head, as shown in Fig. 3, and gave satisfactory results, bearing 250 lb. without showing any signs of distress. It could not be expected, however, to stand the pressure necessary for a lifting-effort of 50 tons; hence an intensifier with a low-pressure plunger $4\frac{1}{8}$ in. in diameter, a high-pressure plunger $1\frac{13}{16}$ in. in

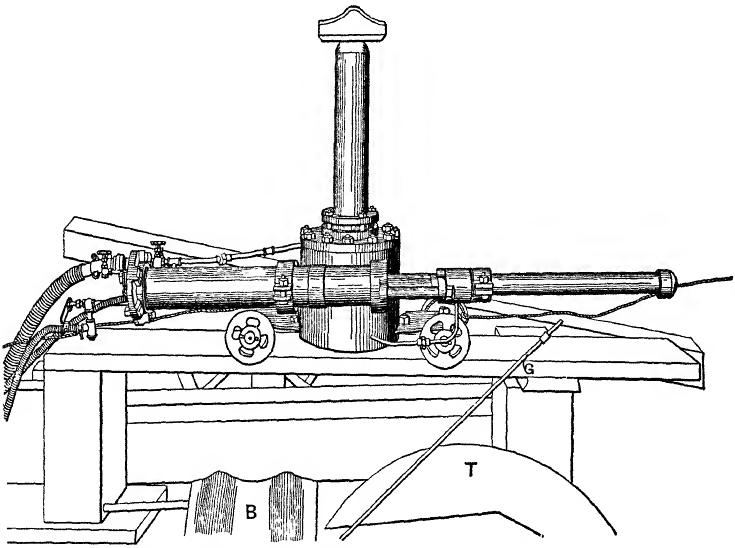


FIG 3.—VIEW OF HYDRAULIC PRESS, PREPARED FROM A PHOTOGRAPH.

diameter, and a 24-in. stroke, was mounted on the press itself, with its center of gravity over the longitudinal center of the press, and connected to the lifting side of *L* by the high-pressure pipe, *H*, as shown in Fig. 1.

By calculation based upon the data given, it will be found that the delivery-pressure due to intensifying was

$$\frac{\text{Area of low-pressure cylinder}}{\text{Area of high-pressure cylinder}} \times 250 \text{ (the line-pressure)} =$$

1,300 lb. per sq. in., and that the displacement of the high-pressure cylinder per stroke was the area of that cylinder $\times$ $24 = 61.9$ cu. inch. Hence the intensifier would lift the ram

a distance of 0.75 in., and exert a force of 52 tons, neglecting friction, weight of ram, etc.

The idle part of the stroke being effected and all slack taken up by the line-pressure, practically all of the high-pressure ram-movement could be utilized for pressing up the crown.

The mode and sequence of operations was as follows: The part of the furnace where operations were to begin, and at the places shown to be out of round by template, *T*, Fig. 3, were heated to low-red by a wood-fire, contained in a sheet-iron pan

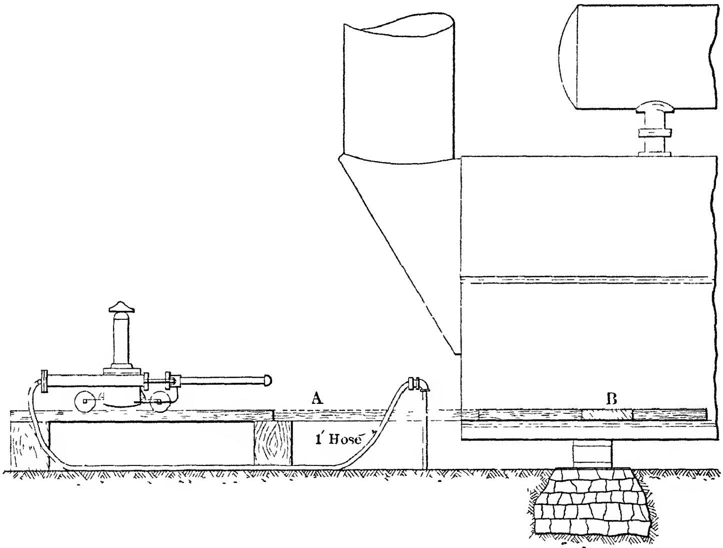


FIG. 4.—SKETCH SHOWING THE GENERAL METHOD OF OPERATING THE HYDRAULIC PRESS.

or basket, fitted with long handles to facilitate its easy handling. Directly under the spot to be pressed up was placed plate *B* (Figs. 3 and 4), a casting roughly fitting the corrugations of the furnace. This plate is 12 in. wide and fitted the tread of the truck-wheels on the press.

A short piece (say, 2 ft.) of plank, placed beyond and abutting against the plate, formed an extension-track; and longer pieces similarly laid to connect the plate with the bench, upon which the press is withdrawn and kept out of the way during the heating, made a good track upon which the press could be

readily moved in and out of the furnace (see Fig. 4). Plank *A* was taken out of the way when not in use.

When the ram was in its lowest position, as shown in Figs. 1 and 2, the plate, *B*, which was set in a ball-and-socket seat, and held in place by a loosely-fitting dowel-pin, had 2 in. clearance from the top of the furnace.

When a long low heat had been secured the fire-basket was taken out, and the plank, *A*, put in the furnace. The press was then put into place with the cylinder over the plate, *B*, and pressure was admitted through the $\frac{1}{4}$-in. globe-valve, *Y*, from the pressure-header, *O*, to the lower end of *L*. This raises the ram and block, B_1, up against the furnace, and springs, *L*, down half an inch, when the rounded bottom comes in contact with *B*, from which it had previously been held apart by the spring-plates, *S S*—all shown in Figs. 1 and 2.

In filling the lower part of *L*, the water also fills the high-pressure cylinder, *D*, through *H*, and acting on plunger, *P*, has sufficient force to drive it back to the position shown in Fig. 1.

When the pressure-block is hard up in place, water is admitted from *O* to low-pressure cylinder, *R*, through valve, *W*, which advances the plunger, *P*, in *D*, forcing the water back through *H* to *L;* escape through the admission-pipe being prevented by a check-valve placed between the admission-valve and cylinder.

The pressure in *L* is now 1,300 lb., or a total lifting-effect of 52 tons on a $10\frac{1}{8}$-in. piston.

As soon as the plunger, *P*, reaches the end of its stroke, valve, *W*, is closed and valve, *X*, is opened, when the line-water coming into *L*, through admission-pipe and again filling *D*, forces *P* back to the first position ready for another stroke. This action may be repeated indefinitely, and at each heat two corrugations or about 16 in. are treated.

By testing the curvature with template, *T*, tilting the press slightly from the vertical when necessary, and by comparing the vertical and the horizontal diameter with the caliper-gauge, the curvature of furnace may be brought up to a practically true circle.

The variation certainly need not exceed $\frac{1}{16}$ of an inch.

Details of Construction.

Low first cost, being necessary in making this experimental machine, stock on hand was utilized wherever possible. In fact, only the main cylinder, the head and plates, *B* (Fig. 3), and, B_1 (Fig. 1), together with the two caps for the intensifier, were purchased,—in all, about 300 lb. of rough castings.

The ram was made of a piece of 4-in. double extra heavy pipe—a size sometimes used in the mine for column-bars—turned to 4.25 in. in diameter. Cylinder, *D*, is a piece of 2-in. standard brass pipe specially threaded with 15 threads to the inch at each end. Cylinder, *R*, is simply a piece of 4-in. standard iron pipe, bored with one cut to $4\frac{1}{8}$ in. fitted with a piston from an old 6- by 4- by 6-in. duplex pump screwed on to a piece of $1\frac{7}{8}$-in. diamond-drill tubing, turned down to $1\frac{13}{16}$ in. and plugged, forming the plunger, *P*. Standard $\frac{1}{4}$-in. globe and angle-valves were used for controlling admission and exhaust, and $\frac{1}{4}$-in. standard iron pipe for all cylinder connections, except for *H*, which is $\frac{1}{8}$-in. standard. I am aware that it is pressing the limit somewhat to put 1,300 lb. pressure on $\frac{1}{4}$-in. standard pipe, but, as it stood up to the work, it shows what may be done under stress of circumstances. Single-cup leather packing of the usual form was used on the lifting- and intensifier-plungers. The cost of the press, figuring material and labor, at cost, was $67.

All the work of building a press of this kind may be readily handled in any mine machine-shop equipped with a drill-press and a lathe capable of swinging 18 in. or more. The patterns were made by a mine-carpenter having no knowledge of pattern-making.

The entire cost of repairing the two furnaces, including dismantling and refitting, cost of press, but not the superintendence, was $187. The time taken for the work was eight days.

This cost was not considered excessive, in view of the fact that a pair of new furnaces would have cost $700, each, f. o b. Rossland, to say nothing of the expense involved in changing the furnaces, and remembering that, unless replaced or repaired, the old ones were not considered safe at the steam-pressure necessary for the economical operation of the engines.

The cost is much less, and the operation more satisfactory than that of a hydraulic jack to do the same work.

Remarks.

Since a hydrostatic head of considerable force is frequently not available, a small boiler-feed or tank-pump might be utilized to furnish the necessary pressure; or by rigging up a temporary accumulator, a hand force-pump could be used.

A somewhat lower water-pressure could be employed by increasing the size of the main cylinder, but, if this be carried to extreme, it will sacrifice mobility and ease of operation, two very essential features when a hot furnace is waiting to be repaired.

Instead of the sheet-iron pan and wood-fire, an oil-burner could be used to excellent advantage, if the price of fuel-oil permits.

In order to insure against oversetting (an advisable precaution if inexperienced help is to be employed), a hole may be drilled in the main-cylinder wall at such a height that it will be uncovered, releasing the pressure, when the piston has risen a proper distance. The intensifier is clamped to the main cylinder by two straps of 2 by $\frac{5}{8}$-in. iron bolted to pads, cast on the side of the cylinder for the purpose.

Furnaces should be tested with template, T, in order to determine at what points the collapse has started, and the heat should then be applied at the points indicated. In every case the action of the press will be in a nearly vertical direction; the application of the heat at the places of deformation allowing correction at these points.

After having been in service for 14 months from the time the above repairs were made, the furnaces were calipered and found to be practically perfect in shape.

A Special Form of Slag-Car.

BY L. J. W. JONES AND B H. BENNETTS, TACOMA, WASH.

(Washington Meeting, May, 1905)

THE removal and disposition of large quantities of slag from blast-furnaces is a question of great importance in the design of works, and various methods have been devised, from time to time, in order to take the best advantage of local conditions.

With blast-furnaces treating copper-ores or lead-ores, it is necessary to use a fore-hearth, or matte-settler, in order to collect, if possible, every particle of valuable matte which, otherwise, would be carried away with the out-flowing slag. In all of these cases, the slag overflowing from the fore-hearth is caught in pots and then conveyed to the dump. If the slag is of no value and the necessary water-supply, grade and dumping-space be available, the disposal of the slag by granulation is by far the cheapest and best method. It involves a minimum of labor, both at the furnace and at the dump; and it permits a continuous outflow of slag from the furnace or settling-pot, thereby avoiding frequent tapping and plugging. When the conditions of water-supply, grade and dump-area will not permit slag-granulation, there are three other methods in common use. Large steel or cast-iron pots, or ladles, supported by trunnions on heavy cars which are moved by steam-, air-, or electric locomotives; some type of mechanical conveyor; and small pots or buggies moved by hand. The pots on the slag-cars are generally circular or oval in shape, and each one contains from 15 to 40 or more cu. ft. of molten material. The mechanism for tipping them is more or less elaborate; and, as a general rule, the slag is dumped alongside, and quite close to, the track. They are more or less costly to construct and to keep in repair, and, in order to use them to best advantage, it is necessary to have a good elevation of track above the dumping-ground; furthermore, the rails must be of heavy weight, and well-supported on heavy ties. Other disadvantages of the slag-pots are—1, that the slag cannot be removed continuously

from the furnace, which must therefore be frequently tapped and plugged; 2, that the resultant cone-shaped masses of slag are unwieldy and difficult to handle; 3, that the slag is dumped at the side of the car only, and 4, that the pots cannot be brought close to the slag-spouts. For small plants the method of slag removal by large pots is too expensive, small pots moved by hand, or larger pots of from 15 to 30 cu. ft. capacity, hauled by horse or mule, being generally used to convey the slag from the furnace to the dump.

In most of the older plants the tap-holes are only 4 or 5 ft. above the ground-level, and the height of the slag-pot and car is, therefore, limited to this small dimension. In plants of modern construction, however, as at Butte and Anaconda, Mont., the slag-spout is of sufficient elevation to allow the use of larger pots or ladles.

At the copper blast-furnaces of the Tacoma Smelting Company, at Tacoma, Wash., a fore-hearth, 14 ft. in diameter, was used to collect the matte. The slag overflowing therefrom was formerly granulated by a stream of water, resembling the practice at the Anaconda furnaces. The ground-level, however, was only a few feet above tide-water, which required the use of a belt-elevator in order to gain sufficient height so that the granulated slag could be washed into the Sound. The water-supply was small, and there was so much trouble with the belt-elevator that its use was finally abandoned. Another reason for its abandonment was the fact that the granulated slag could not be used for filling-in or building-purposes, and the company needed to reclaim a large area of ground, in order to provide for an extension of its plant. After experimenting for some time, we designed a special slag-car to run over the 18-in. gauge industrial railroad with which the works was equipped, of the following description:

As is shown in Figs. 1 and 2, the pot itself, shaped like a rectangular scoop, has the discharge-end projecting well beyond the center of the car, so that when the pot is turned and tipped, the slag will be thrown well clear of the tracks. The cast-iron pot, weighing about 1,100 lb., is mounted on a cast-iron turn-table, supported by an I-beam truck, equipped with 2-in. square axles bolted to the frame, with the ends machined down for the journals. The wheels of chilled cast-iron, 11 in. in diameter, have roller-bearings which are held in place by heavy

FIG. 1.—METHOD OF DISCHARGING THE SLAG-CAR.

FIG. 2.—METHOD OF DISCHARGING THE SLAG-CAR.

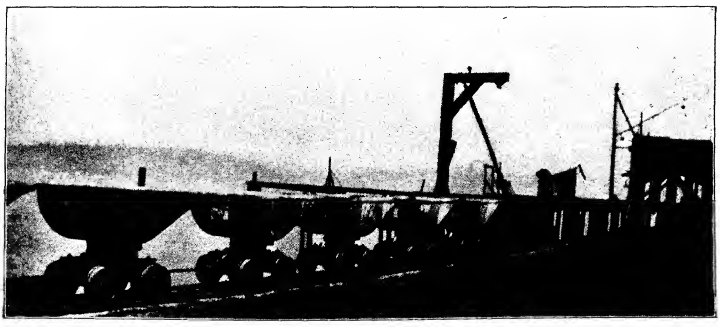


FIG. 3.—TRAIN OF SLAG-CARS AND ELECTRIC MOTOR.

cast-iron washers, and a wide tread. Each car complete weighs 1,510 lb. and holds 1,600 lb. of slag. The cost of each car made in the shops of the company was $75. So far they have been in use for 18 months; and, apart from the removal of a few bowls which were cracked through carelessness, no repairs have been needed. The pot is dumped quite easily, as is shown in Figs. 1 and 2.

A train of slag-cars, generally 12 in number, is drawn by an electric motor to the dump. The motor-man, without detaching the cars, trips the latch, revolves each pot on its turn-table to the desired position by means of a long iron-bar fitting into a socket at the back of the pot, and, by raising the bar, tips the pot and discharges its contents. The shell, or solidified crust, next to the sides and bottom, is released and discharged by tipping the pot with a jerk; but, if the pot be gently tipped, the shell will remain in it. Fig. 3 shows a train of slag-cars with the electric motor.

A special advantage of this shape of pot is, that the cars may be run in a continuous line without any intervening space between adjacent pots. This arrangement is of great value in receiving slag from a furnace which discharges continuously. There is no spilling or slopping on the truck or track. One man can haul out to a distance of 1,000 or 1,500 ft., tip and return to the furnace, 30 of these cars per hour, which is equivalent to 576 tons of slag per day. The slag, either liquid or solid, may be dumped forward, backward, or to one side or the other of the truck; in the latter case the slag is thrown at least 2 ft. beyond the ties; and, by using rails as skids, the solid slag-cake may be landed 18 or 20 ft. from the track. The cars are connected by an automatic coupler, which holds them at a given distance apart, and enables the train to be pushed or pulled without lost motion. Moreover, the automatic coupling-device removes the danger which is present when the cars are connected by hand.

Sixty of these new cars are used at present in the lead- and copper-plants of the Tacoma Smelting Co., replacing the older and more troublesome methods formerly employed.

These cars, slightly altered, are used for the base bullion cast from lead-furnaces. The dross can be separated more easily and the resultant bullion is cleaner than that made in the ordinary manner of casting.

Tin-Mining and Smelting at Santa Barbara, Guanajuato, Mexico.

BY A. H BROMLY, MEXICO CITY, MEXICO.

(Washington Meeting, May, 1905)

THE small agricultural village of Santa Barbara, in the State of Guanajuato, has been the center of spasmodic tin-mining operations during recent years. The deposits, so far as I know, are unique, and a few brief notes may be of interest.

Santa Barbara, about 12 miles west of San Felipe station on the Mexican National Railway, and at an elevation of 2,400 m. above sea-level, is situated in a flat valley extending east and west, and bounded north and south by broken rugged hills rising about 330 m. above the general level of the valley.

Tin-mining operations have been conducted at the Queensland mine, near this village. A small concentrating-mill was erected and attempts were made to smelt the ore in reverberatory furnaces.

The country-rock of the district for many miles is rhyolite of great thickness. There are some local variations due to differences in cooling, or subsequent alteration or impregnation; but throughout the whole district the principal constituents of the rocks remain the same, viz., free silica, orthoclase-feldspar and sanidine. The latter is especially marked. The crevices and joints of the rock are frequently filled with calcedonic and opalescent quartz.

The ore-formation at the Queensland mine is of an unusual nature, consisting of cracks in the rhyolite which have been filled with clay. This phenomenon is largely developed over a width of from 80 to 100 m., in which the principal fissuring follows an approximate direction of north and south. The average dip ranges between 70 and 80 degrees. Some of the fissures hold sufficiently true for a time to afford the impression that they are due to dynamic causes, or earth-movement. This may be true of some of the north by south fissures; but considering

the extraordinary ramification of joints and crevices running in every direction, and the strong resemblance many of them bear to cooling-cracks that have been formed while the rock was in a partially plastic condition, it is probable the shattering was due to some local stress increased by the contraction of cooling.

The clay-filling of these cracks varies in width from a mere joint to a few inches, averaging about 3 in. Occasionally, owing to local bulges, there have been formed pockets or bunches of very limited dimensions. The color of these stringers varies from a whitish to brown, red, and in some cases to a curious scarlet, giving the clay a resemblance to sealing-wax. This latter appears to be generally barren. Most of the stringers have a tendency to die out if followed in any given direction, but often it is found that they have branched off and made into cross-joints, to shoot off again within a few feet.

These clay-stringers carry a mixed mineralization, principally in the form of iron and tin oxides. The iron very largely predominates, and, on the whole, it would be correct to describe the deposit as one that carries a small percentage of iron contaminated with tin. Some small shoots occur in which the minerals have segregated out as small kernels, or kidneys, or have frozen to the walls.

The tin-ore occurs in at least three conditions. 1. Fine tin oxide comparatively pure disseminated through the clay. 2. Intimately associated in varying proportion with iron oxide, and 3. In microscopical condition, so fine as not to be found in any system of concentration, hand or otherwise. Experiments upon the mill-tailings indicate the presence of this fine mineral in the particles of sand resulting from the unavoidable inclusion of country-rock in the ore. Tests upon the waste sorted out before milling show a low percentage of iron with some tin. It seems likely, therefore, that the country-rock in the neighborhood of the stringers is also impregnated with extremely fine mineral. It is possible that this impregnation extends to a slight degree throughout the entire country-rock in the mineralized zone, but, although this point has not been investigated, it certainly does not exist to a payable degree.

As is commonly the case with tin-ore deposits, there has been a superficial enrichment due to surface-concentration. A small

amount of alluvial tin-ore is gathered from the gullies of the district, but in very limited quantities, which consists mainly of kidney-ore of varying quality, from fair purity down to practically pure iron only. A specimen of alluvial kidney-ore selected for its purity, and assayed by me, gave 65.7 per cent. of metallic tin.

The upper workings of the Queensland mine gave promise of yielding an average of from 2 to 3 per cent. of metallic tin, but the general average of the whole mine to a depth of 40 m. is about 0.4 per cent. only. In the bottom levels the proportion of tin to iron is extremely low.

In the district there are a number of superficial deposits of a different character, carrying tin and cinnabar, now mostly worked out and abandoned. These deposits consist mainly of impregnations within small limited areas of local metamorphism, in which the feldspar and sanidine predominate with a deficiency of silica, which seem to afford strong evidence of either pneumatolytic or solfataric action.

The occurrence of tin-ore with a total absence of granitic rocks, and the usually associated minerals, is interesting. If the mineralization has resulted from deep-seated causes, it may be that granitic rocks are to be found below the rhyolite. The evidence available, however, would indicate that the underlying rock is probably slate. The shallow depth of the native workings is conclusive evidence of the superficial and limited extent of the paying ore. The latter was washed in *planillas* and smelted in small furnaces with charcoal; an industry that survives to a limited extent to-day.

A sectional elevation of this furnace is given in Fig. 1, and a view of it while in operation in Fig. 2. The main portion of the furnace is built of adobe, but the shaft is of stone with a refractory lining. A double bellows, worked by two men, provides the blast; one side being pushed in while the other is pulled out. Each bellows has a separate tuyere, the hole at the back of the furnace receiving them is oval and sufficiently wide to permit the occasional insertion of a cleaning-bar. Since the tuyeres point directly to the tap, which is always open, the blast escapes by the latter instead of by the shaft, and there is much sublimation and loss. The tap is the full width of the bottom of the furnace, i.e., 9 in., and the fur-

nace-man keeps it clear with an iron-shod tapping-iron. With the same tool the cakes of slag accumulating from the tap are broken up and removed. A heap of charcoal is kept burning in front of the tap-hole, and the tin trickling down into the shallow well is occasionally lifted back with the tapping-iron into the charcoal pile, and, remelting, runs down again, each time a little purer. Concentrates and fine ore are wetted and charged in lumps a little larger than a hen's egg.

The work is done by contract and the average time for twice smelting 150 kg. of ore is 16 hours. Two men blow for 45 min. each, and are then relieved by another two for an equal period. It thus takes 4 men to provide the blast. In addition to the furnace-man there is a charger attending to the feed. The rates paid per 16 kg. of ore treated are:—Furnace-man, 12 cents (Mex.); blowers and charger, 8 cents (Mex.).

The following data pertaining to results from various classes of ore were supplied by the owner of the furnace:—

Metal de correa, ó nacar (a black kidney-ore, evidently very impure). Smelting 150 kg., plus 50 kg. *plomillo* (rich slag), yields 50 kg. tin and 75 kg. *plomillo*, using 2 of charcoal to 1 of ore.

Reventón (good quality kidney-ore, the best the district affords). Smelting 150 kg., plus 100 kg. *plomillo*, yields 100 kg. tin and 50 kg. *plomillo*, using 2 of charcoal to 1 of ore.

Espesa (a crystalline mixture of tin and iron). Smelting 150 kg., plus 20 kg. *plomillo*, yields 10 kg. tin and an undetermined quantity of *plomillo*, using 3 of charcoal to 1 of ore.

A sample of concentrates from the Queensland mill, known to run about 15 per cent. of metallic tin by wet analysis, and weighing 100 kg., was washed in a batea down to 50 kg. and smelted in this furnace. It required 6 hours to run 50 kg. of concentrates, including remelting of slags, with a charcoal-consumption of 100 kg. The produce was 1.4 kg. of tin and 8.5 kg. of impure tin, hardhead and dirty slags. Probably if further treated the recovery in clean tin would have been about 6 kg., with a loss of 9 kg. on the original content of 15 kg. The furnace- and washing-losses were therefore about 60 per cent. of the total tin in the ore. The cost of smelting 50 kg. of ore was $5.94 (Mex.).

This Mexican furnace is inferior in design to the Portuguese

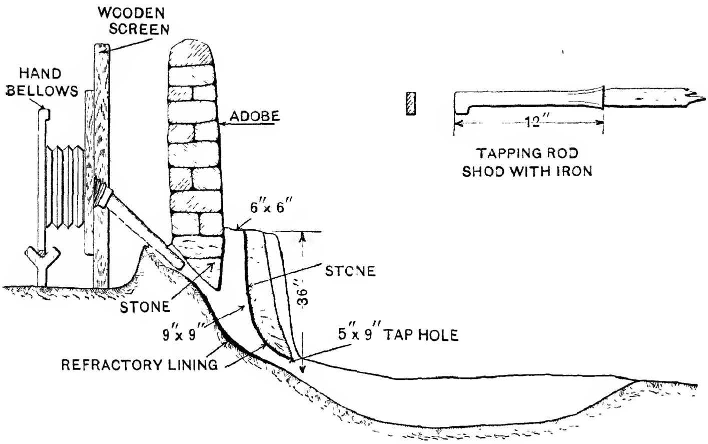


FIG. 1.—CHARCOAL-FURNACE FOR SMELTING TIN-ORES AT SANTA BARBARA, GUANAJUATO, MEXICO.

FIG. 2.—VIEW OF CHARCOAL-FURNACE SMELTING TIN-ORES AT SANTA BARBARA, GUANAJUATO, MEXICO.

type;[1] but, in comparing their respective duties, it must be remembered that the Portuguese furnace treated the purest tin-ore possible to obtain, while the Mexican furnace treated very impure and poor ores.

Most of the tin-ore of this district is exceedingly difficult to treat. Due to the intimate association of tin oxide with iron oxide, and much of the former being exceedingly fine, a good separation cannot be made by concentration, and the losses are very heavy. Roasting and re-concentrating is useless, and the impurities are insoluble in acids. An attempt at concentrating has been made at the Queensland mine, using a Krupp ball-mill in conjunction with a Wilfley table, followed by a Wilfley slime-table. The results were practically unsatisfactory, an extraction of 29 per cent. only on 0.4 per cent. ($6 Mex.) ore, with a concentrate of the average value of 15 per cent. metallic tin, being obtained

Incidentally it may be useful to note that this mill affords an excellent object-lesson of the limitations of the ball-mill as a re-grinder. A No. 2 Krupp is arranged to crush wet through 25-mesh bronze-wire screens. The original ore is a fine material consisting of desiccated clay with stones of country-rock. To this is added the middlings, or coarse sands, returned from the Wilfley, which have already passed the screens. The bulk of the feed immediately passes the holes in the armor-plate, and packs at the back of the screens. As the mill is doing but little crushing, there is insufficient vibration to clear the screen and the output is heavily reduced owing to the choking of the wires. Under such circumstances the mill acts mainly as a pug-mill, the interior being choked with a mass of pug and sand, much of which passes and re-passes several times before being sufficiently reduced to pass to the slime-table; thus aggravating the evil.

A screen-analysis of mill-product gave:—20- to 30-mesh, 13.75; 30- to 40-mesh, 22.5; 40- to 50-mesh, 15; 50- to 60-mesh, 11.25; 60- to 80-mesh, 8, and below 80-mesh, 30.5; making a total of 101 per cent.

The arrangement of the plant admits of very obvious improvement. Doubtless, better knowledge would have given better results, but I strongly doubt whether the Queensland

[1] *The Mineral Industry*, vol vii., p. 717 (1898).

ores, even if sufficiently abundant instead of the reverse, would have commercial value.

The following are analyses of ore from the Queensland mine: No. 1, a selected specimen from surface-workings, high in tin; and No. 2, a representative sample of the general run of mine. *No.* 1:—Al_2O_3, 5.8; insoluble (SiO_2), etc., 55.2; Fe, 5.4; Sn, 6.2; Mn, trace. Total, 72.6 per cent. *No.* 2:—SiO_2, 58.1; Sn, 0.43 per cent.

A sample of a small pocket, found at 20 m. depth in Queensland mine, yielded by hand-washing a mixed concentrate of iron and tin amounting to 21 per cent. Upon assay this concentrate yielded 18.1 per cent. of metallic tin, or 3.8 per cent. of metallic tin on the original ore. Material of this character is exceedingly difficult to assay.

The following is an analysis of representative samples of Queensland concentrates made by S. D. Bridge, of Monterrey:

	Per Cent	*Probably combined as —*	Per Cent
Moisture,	0.48	Moisture,	0.48
Loss by ignition,	1.36	Combined water,	1.01
Silica,	37.08	Silica,	35.99
Alumina,	2 72	Aluminum silicate,	3.79
Iron,	22.91	Iron sesqui-oxide,	32.74
Tin,	17.12	Tin oxide,	21.78
Lime,	0.21	Calcium carbonate,	0 35
Magnesia,	0.32	Magnesium carbonate,	0.67
Lead,	0.82	Lead sulphide,	0.50
Zinc,	0.91	Lead oxide,	0.39
Copper,	Nil.	Oxide zinc,	1.14
Sulphur,	0 04	Copper,	Nil
	83.97		98.84

Another analysis of Queensland concentrates, made by Dr. James B. Hard, of Mexico City, Mex., gave:—

	Per Cent	Per Cent
Stannic oxide,	19 13	— Metallic tin, 15.08
Calcium oxide,	8.24	
Ferric and aluminum oxide,	29 84	
Silicon oxide,	36 35	
Sulphur trioxide,	1.85	
Water of crystallization,	1 64	
	97.05	
Undetermined (phosphorus, manganese, alkali, etc.,	2 95	
	100.00	

Cyaniding Silver-Gold Ores of the Palmarejo Mine, Chihuahua, Mexico.

BY T. H. OXNAM, CHINIPAS, CHIHUAHUA, MEXICO.

(Washington Meeting, May, 1905.)

INTRODUCTION.

THE predominating value of the ores now being treated by the Palmarejo and Mexican Gold Fields, Ltd., is silver, although some gold also is carried.

The present method of treatment consists of wet-crushing and concentrating, followed by the cyanidation of the unroasted sands and slimes. The sands are treated by leaching, and the so-called "accumulated slimes" by a system of agitation and decantation.

It is only within very recent years that the cyanidation of unroasted silver-ores has been commercially successful. In fact, at the time operations were begun at the cyanide-plant at Chinipas, February, 1902, I knew of no other leaching-plant treating similar ores successfully. The cyanide treatment of the Palmarejo ores differs but little from the ordinary practice in cyaniding gold-ores; and perhaps but little, if any, new information concerning the metallurgy of silver is to be gleaned from it.

PALMAREJO MINES.

The Palmarejo mines are located in the southwestern part of the State of Chihuahua, Mexico, on the foothills of the Sierra Madre mountains, at an elevation of 3,200 feet. The mills, 12 miles distant, are situated on the Chinipas river, near the town of Chinipas, which is about 150 miles northeast of Agiabampo, on the Gulf of California. Supplies are shipped via this port as this route is the best and most direct to the property.

The ore-bodies in the Palmarejo mines have been deposited along a series of rock-fractures, caused by an intrusion of eruptive rock. The most important of these fractures or fissures, both in width and value, are the Prieta and Blanca veins, which

intersect each other on the surface, at a point called the *Descubridora*, or discovery; and underground, in the main working-tunnel (*Socorro*) about 800 ft. from its entrance. (See Fig. 1.)

From the junction of the two veins, the Prieta strikes almost due east, and the Blanca, south, 51° 30′ east, dipping at an angle of 50° to the west.

The Prieta vein in places is fully 75 ft. wide between walls. The ore, however, is frequently in two sections, known as the

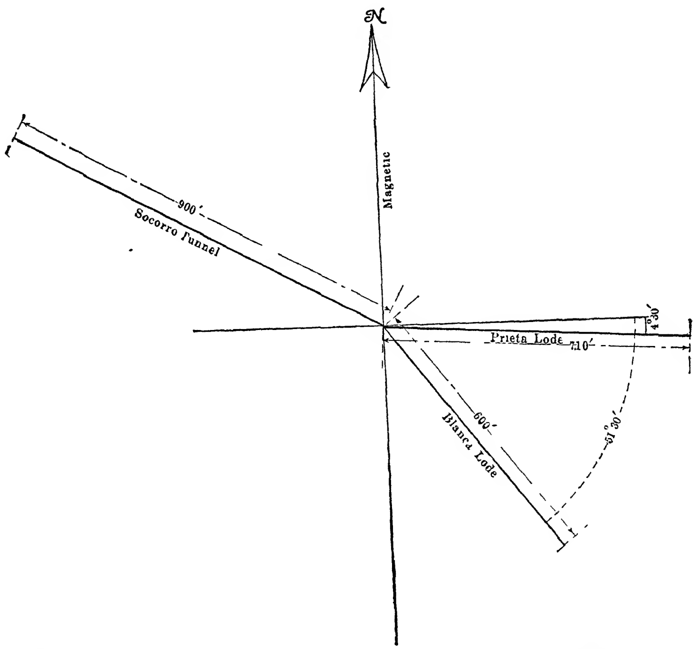


FIG. 1.—PLAN; SHOWING BEARINGS OF BLANCA AND PRIETA LODES, AND SOCORRO TUNNEL.

foot-wall and hanging-wall sections of the vein, with a horse of country-rock, from 10 to 30 ft. thick, between them.

Stoping has been done on both the foot-wall and the hanging-wall sections on the course or strike of the vein, for 2,000 ft. in length, and while the values are continuous the better grade of ore makes in chimneys or shoots, varying from 75 to 300 ft. in length.

The Blanca vein which varies from 4 to 12 ft. in width has been mined for a distance of 850 feet. At the junction of the

veins the bonanza of the mine was found, which has been worked for more than 800 ft. in depth, and has yielded an enormous amount of money.

The records in the office of the company show that these mines have been worked for more than a century.

The ore delivered to the mill consists essentially of a siliceous matrix, throughout which is disseminated a small percentage of pyrite. Black manganese oxide and calcite are present in varying proportions, and very small quantities of antimony and arsenic, together with traces of bismuth, also occur. Occasionally traces of copper and zinc are found.

The major portion of the silver occurs in the form of argentite, though a certain amount of stephanite is present and occasionally small patches of chlorobromide and native silver.

The main storage-bin of the Palmarejo group of mines is connected with the mill by means of a narrow-gauge railroad, 12.5 miles long. The mill is about 1,300 ft. lower than this ore-bin, consequently the entire road is on a moderately heavy grade—the heaviest slightly exceeding 4.5 per cent. The gauge of the road is 30 in.; two weights of rails are employed, one being 35 lb. and the other 25 lb. per yard. Two English locomotives are in service; one a 22-ton engine hauling 14 cars, and the other, an 18-ton engine, hauling 9 cars. Each ore-car has a carrying capacity of 4.5 tons. Under normal conditions, from 4 to 4.5 hours are required for making a round-trip.

Mill and Cyanide-Plant.

The 50-stamp mill and cyanide-plant is situated on the edge of the Chinipas river, about 1.5 miles eastward of Chinipas, at a place known locally as "El Zapote." Water-power furnished by the Chinipas river is used to run the mill, slime-plant and machine-shop. A masonry conduit, about 11 miles long, conducts the water to a pen-stock a short distance above the mill, thence through a steel pipe, about 1,100 ft. long, tapering from 48 in. in diameter at the pen-stock to 22 in. in diameter in the wheel-pits, to four 6-ft. Pelton wheels under a 97.5-ft. head.

Old System of Milling.

The mill was originally erected as a dry-crushing, roasting and pan-amalgamation plant and was operated as such until

the middle of October, 1901. On my first visit to this property, December, 1900, the mill-operations and methods of ore-treatment were substantially as follows:—

The ore was drawn from the main storage-bin at the top of the mill over iron grizzlies to the five 7-in. by 10-in. Blake crushers, running 250 rev. per minute. From the large storage-bin beneath the crushers, the ore, after the addition of 5 per cent. by weight each of salt and sulphurets, was conveyed to three White-Howell cylindrical driers, each 18 ft. long and ordinarily rotated at 6 rev. per min., the speed given them, however, naturally depending upon the percentage of moisture contained in the ore passing through them at the time. Two driers easily handled the quantity of ore crushed by the stamps, even in the rainy season.

Each drier discharged into a small storage-bin, from which the ore was conveyed in half-ton cars to the hoppers of 10 Challenge ore-feeders. The stamps when equipped with new shoes weighed 850 lb. and dropped from 4 to 7 in., according to the condition of the shoes and dies, at a speed of from 85 to 90 drops per minute. Both the shoes and dies were cast on the premises, in the foundry of the company. Mortars were of the wide, double-discharge pattern and 20-mesh brass-wire screens were used. The duty was from 1.25 to 1.5 tons per stamp per 24 hours.

The dry pulp, discharged through the battery-screens, was carried by means of a series of belt-conveyors and elevators to three revolving cylindrical roasters of the White-Howell type, lined with fire-brick made in the vicinity. These roasters were 27 ft. long, 2 ft. 9 in. inside diameter at the feed and 3 ft. 6 in. inside diameter at the discharge, and were rotated at an average speed of 3 rev. per minute. The roasted ore was wheeled in cars to a large brick storage-pit, where it was allowed to remain for from 18 to 36 hr., after which it was drawn out on the cooling-floor and sprinkled down with a hose.

Daily tests made on average samples of the roasted product, taken as it left the roasters, showed that about 80 per cent. of the silver was rendered soluble in sodium hyposulphite. When cooled sufficiently to handle, the roasted material was shoveled or raked into cars and trammed to the 20 amalgamating-pans of the McCone pattern, each 5 ft. in diameter. The usual

charge consisted of 2,800 lb. of ore, 150 lb. of quicksilver, 15 lb. of salt and 1.7 lb. of bluestone. The quicksilver, salt and bluestone were added as soon as a pan was charged. The pans were run at an average speed of 68 rev. per min. and were kept at a temperature of from 100° to 110° F. by means of steam added through a small pipe directly to the material being treated. After from 6 to 8 hr. treatment, the pans were discharged into 8-ft. settlers; each two pans being provided with one settler. From the settlers the tailings were discharged into 10-ft. agitators, one agitator receiving the discharge from two settlers. These agitators, however, for some time previously had not been used as agitators proper and were serving merely as mercury-traps. The tailings escaping from the agitators were carried by the water-race to the Chinipas river.

While the process of treatment outlined above has given very satisfactory results with many ores of similar nature to the Palmarejo ores, though perhaps in districts more favorably situated for freighting-facilities, it had never proved to be a commercial success on the ores of this company, due chiefly to the unusually high working-expenses. Owing to the isolated position of this property, freighting-expenses were a very heavy item, as, in addition to steamer- or railroad-transportation to the nearest sea-port, practically all of the freight had to be transported by wagon for a distance of about 110 miles, and the last 60 miles into the property is by way of rugged mountain trails, permitting only mule-back transportation. It can thus be readily seen that the freighting-cost alone proved a very considerable item. Due largely to this reason, combined with the fact that the quantity treated was comparatively low, the expenses of maintenance and repairs per ton treated were very high.

A considerable percentage of the ore passing through the roasters was carried into the dust-chambers and flues, a portion of which escaped and was entirely lost. The material caught in the flues and dust-chambers was periodically removed and treated in the pans without further roasting. This semi-roasted flue-dust was given a longer and special treatment, but the extraction obtained from it was always considerably lower than that obtained on the well-roasted material.

Another very serious source of loss was in the volatilization

of a considerable portion of the silver-content during the roasting. In the year ending June 30, 1901, slightly more than 22,000 tons were crushed in the mill, comprising 20,000 tons of ore and 1,000 tons each of salt and sulphurets. Five per cent. of the weight of the ore was lost as moisture in passing through the driers and an additional 6 per cent. by weight was lost between the batteries and the pans, such percentage being due almost entirely to losses by volatilization and dusting while passing through the roasters. The assay-results for this year showed that approximately 12 per cent. of the total silver contained in the ore was lost by volatilization during roasting. The total working-cost for this period was $24.20 per ton, divided approximately as follows:—Mining, $8.12; milling, $14.32; ditch, $0.60; railway, $1.16; total, $24.20. The average assay for the year of the ore as delivered to the mill was 30 oz. of silver. The average of the ore as charged into the pans was 25.4 oz. of silver. It was always considered practically useless to send, to the mill, ore which carried less than 30 oz. of silver per ton. The average extraction of silver for the year as indicated by bullion-returns was approximately 77 per cent. of the value of the material panned, this being equivalent to 66 per cent. of the total silver-value of the ore crushed. Ordinarily, the ore was not assayed for gold and no special attention was given to effect its recovery. While a part of the gold was caught and saved in the pans, it is more than probable that the major portion contained in the ore was entirely lost.

Experiments With Wet-Crushing, Concentration and Raw Pan-Amalgamation.

Shortly after my return to this property in March, 1901, at which time I assumed the management, a series of experiments was commenced to determine, if possible, a better method of ore-reduction which would promise that future operations could be conducted on a financially successful basis—a condition which up to that time had not been attained.

In order to effect such a change, it did not necessarily follow that a higher percentage of extraction need be obtained. The difficulty might be solved by the adoption of a treatment whereby the quantity of ore treated would be substantially increased, while effecting at the same time a material reduction

in the operating-cost per ton, although the percentage of values recovered be no more, or might be even less, than that obtained under the old system.

With this object in view, two series of experiments were conducted; one, on the treatment of the different grades of ore by wet-crushing and concentration, followed by raw pan-amalgamation and subsequent reconcentration of the pan-tailings; the other, on the treatment of the ore by wet-crushing and concentration, followed by cyanide-leaching of the resultant sands. Several very careful tests on a practical scale were made along the lines of the first set of experiments and, although the results indicated that, under such a system, operations could be conducted at a certain profit, they were by no means satisfactory and were not as promising as those obtained by the cyanide-experiments.

In the following brief summary of some of the tests made, the ounce of silver is valued at $1.20 (Mex.), and $1 gold (U. S.) at $2 (Mex.).

Test No. 1.

Eighteen tons of ore, of as nearly an average composition as could be obtained of the ore being regularly treated in the mill, were crushed wet through a 30-mesh screen in a specially prepared battery. The pulp was passed over a Wilfley concentrating-table, which removed one ton of concentrates; the tailings from the table were elevated by means of a belt-and-bucket elevator to a series of 3 connected settling-tanks, having a combined capacity of approximately 50 tons. The overflow from the third tank was run to waste. After settling, the ore was transferred to the amalgamating-pans in charges of 1.5 tons and the pans were run for from 6 to 8 hr. at a speed of 68 rev. per min., the temperature of the charge being maintained at about 105° F. During the amalgamation, 200 lb. of quicksilver, 15 lb. of salt and 7 lb. of bluestone were added. The pans were discharged into settlers, from which the material was fed over a second Wilfley concentrating-table, the tailings from which were run to waste.

The ore assayed 29.6 oz. of silver and $4.16 of gold per ton.

18 tons @ 29.6 oz. of silver	= 532.80 oz. of silver	= $639.36 (Mex.)
18 tons @ $4.16 of gold	= $74.88 of gold	= 149.76 (Mex.)
	Total value of 18 tons of ore	= $789.12 (Mex)

First Concentration.—By first concentration, one ton of concentrates was recovered, assaying 126.93 oz. of silver and $17.40 of gold per ton.

1 ton @ 126.93 oz of silver	= 126.93 oz. of silver	=	$152.31 (Mex)
1 ton @ $17.40 of gold	= $17.40 of gold	=	34.80 (Mex.)
	Total value of concentrates	=	$187.11 (Mex.)

The proportion of total values saved by first concentration was 23.70 per cent.

Pan-Amalgamation.—15.7 tons of material were worked in the pans, yielding 96 oz. of silver and no gold.

96 oz. of silver = $115.20 (Mex.)

The proportion of total values saved by pan-amalgamation was 14.59 per cent.

Second Concentration.—100 lb. of concentrates were saved by the second concentration assaying 117.15 oz. of silver and $19.24 of gold per ton.

$\frac{1}{20}$ ton @ 117.15 oz of silver	= 5.86 oz. of silver	=	$7.03 (Mex.)
$\frac{1}{20}$ ton @ $19 24 of gold	= $0.96 of gold	=	1.92 (Mex.)
	Total value of concentrates	=	$8 95 (Mex)

The proportion of total values saved by the second concentration was 1.13 per cent.

In this test there was a loss of 1.3 tons of slimes, equal to 7.22 per cent. of the total weight of ore taken. These slimes, which escaped in the overflow from the third settling-tank, assayed 34.4 oz. of silver and $4.16 of gold per ton. The larger portion of these slimes could, however, have been caught in settling-tanks of large capacity and treated, but the gain which would result from this source was considered as offsetting the losses that would occur in treating the concentrates.

The results of Test No. 1 were—

	Per Cent
First concentration, total values saved,	23.70
Raw pan-amalgamation, total values saved,	14 59
Second concentration, total values saved,	1 13
Total values saved,	39 42

Test No. 2.

A second test on 12 tons of this same ore, conducted along the same lines as Test No. 1, with but slight variations, gave the following results:—

	Per Cent.
First concentration, total values saved, ...	20.40
Raw pan-amalgamation, total values saved, . . .	18.25
Second concentration, total values saved,	2.72
Total values saved, ...	41.37

Test No. 3.

The ore for Test No. 3 was taken from a large dump containing about 40,000 tons of material, which was of so low a grade that it was entirely worthless for treatment by the process used in the mill. Could a process be devised by which this material could be treated at a profit, either by itself or by mixing it with the regular mine-ore, the dump would at once become a valuable asset, as there would be no mining-cost to charge against it and it could be delivered at the mill-bins for $1 per ton. 15.5 tons of this ore, assaying 17.15 oz. of silver and $3 of gold per ton, were taken and crushed wet through a 30-mesh screen. The crushed material received practically the same treatment as in Tests Nos. 1 and 2, with the following results:—

	Per Cent
First concentration, total values saved, . .	23 76
Raw pan-amalgamation, total values saved, . .	19.43
Second concentration, total values saved, . .	1 63
Total values saved, ...	44.82

The results of these tests could not be considered satisfactory, although a careful calculation of the working-cost under this system showed that both the mine- and the dump-ore could be treated at a small profit.

Experiments with Cyaniding Mine- and Dump-Ores.

While the above-mentioned experiments were in progress, extended tests were started on cyaniding mine- and the dump-ores. The results did not indicate that a higher percentage of the silver-content could be obtained than by the old process on the mine-ore, yet they showed that the treatment of both mine- and dump-ores by wet-crushing and concentration, followed by cyanidation of the resultant sands, should prove a commercial success. As a consequence of these experiments, I made a report in June, 1901, on the various tests which had been conducted, strongly recommending that the mill be converted

into a wet-crushing, concentrating and cyaniding-plant. The report being favorably received, the old process was discontinued in October, 1901, and the conversion of the plant begun. The necessary changes in the mill to permit of wet-crushing were effected, the cyanide-plant was installed, and in February, 1902, operations under the changed conditions were commenced.

On account of the lack of sufficient fall between the batteries and the available location for the cyanide leaching-vats, it was necessary that the material leaving the mill be elevated for a height of from 5 to 6 ft., and for this purpose a wooden elevator-wheel, built on the premises, was installed.

The original idea was to subject the entire mill-product to a proper classification by means of a series of steel hydraulic classifying-cones, but owing to the lack of ample fall this idea was abandoned.

The experiments indicated that a thorough oxygenation of the sands during leaching was essential and the advisability of putting in a double-treatment plant, in which half of the vats would be directly superimposed over the other half, was fully considered, but put aside; largely on account of the lack of proper fall, as well as on account of the greater initial cost of installation. This lack of fall between the mill and the cyanide-plant rendered it necessary in several ways to construct the plant along somewhat different lines than would otherwise have been adopted.

Experiments on the ores crushed through 20-, 30- and 40-mesh screens and leaching, after concentration, for varying periods of time, with cyanide solutions containing from 0.25 to 2 per cent. of KCN, resulted in the decision to commence operations by crushing through 20-mesh screens and subjecting the resulting sands to a 10-days' treatment with two strengths of cyanide solution, the weak solution containing about 0.5 per cent., and the strong solution about 1.5 per cent. of KCN; the 10-days' treatment (including filling and discharging) being equivalent to a 9-days' leaching. It was the intention to send the mine- and the dump-ores to the mill in such proportions that the battery-heads would average about 22 oz. of silver per ton.

Certain modifications of the method and alterations of the

plant suggested themselves during the subsequent operations. The working-strengths of both the weak and the strong solutions have been gradually reduced; and the transferral of as many charges as possible from one vat to another at some time during the treatment has been adopted. About two years ago the original leaching-plant was increased by the addition of two leaching-vats and, at the present time, two more leaching-vats are in course of construction. The solution-sump capacity has been increased and several other minor changes effected. Otherwise the leaching-plant and the method of treatment have been altered but slightly since the commencement of operations under this system. Owing to ill-health, I was obliged during May, 1902, to resign the management of this property, remaining, however, in the service of the company as their consulting engineer until May 1, 1903, and during this period making a visit to the property. On the latter date I again assumed the management. The present plant and practice is as follows:—

Present System of Milling.

The ore averaging 6 per cent. of moisture is brought to the mill in trains of from 9 to 14 cars, each car holding 4.5 tons, and is dumped directly into the main upper storage-bin, which has a capacity of approximately 1,100 tons. From this bin the ore is drawn out over 3.5- by 10-ft. iron grizzlies having 1.5-in. openings to the 7- by 10-in. Blake rock-breakers. These breakers run at a speed of 250 rev. per min. and the jaws are usually kept set sufficiently close to deliver a product which will pass through a 2-in. ring.

We have made extended tests on the use of iron crusher-jaws cast in our own foundry compared with manganese-steel castings, and have found the latter to cost slightly less per ton crushed and to give better satisfaction in every way. For some-time past we have been employing the manganese-steel castings exclusively.

The percentage of material falling through the grizzlies varies considerably according to the percentage of mine- and dump-ore being treated. Of the dump-ore, which is very coarse and extremely hard, approximately 90 per cent. goes to the breakers; of the mine-ore, which is much finer and of a softer nature, approximately 50 per cent. goes to the breakers, the

other 10 per cent. and 50 per cent. respectively falling through the grizzlies. A secondary storage-bin of approximately 1,100-tons' capacity receives the ore from both grizzlies and breakers. The ore is then trammed to three small intermediate bins, each of about 50-tons' capacity. From here it is conveyed by means of half-ton cars to the hoppers of the Challenge ore-feeders. This double handling of the ore is inconvenient, but is rendered necessary because of the construction of the mill which, as has been stated, was originally erected to conform to different requirements.

The stamps when equipped with new shoes weigh 850 lb., distributed as follows:—Stem, 350; tappet, 130; boss-head, 215; shoe, 155; total, 850 pounds.

The stamps drop a distance of from 6 to 7 in. 100 times per min., the order of drop being, 1–3–5–2–4; 20-mesh brass-wire screens, No. 26 wire, are used and the height of discharge is kept as nearly as possible at 2 inches. The stamp-duty is from 2.75 to 3.25 tons per 24 hours. The average stamp-duty would doubtless be somewhat increased by the installation of narrow mortars of the Homestake pattern. The same wide, double-discharge mortars used in dry crushing are still in service. The back-discharge of these mortars has been closed by a blind screen, and cast-iron liners have been introduced into the ends and backs of the mortars, thus reducing their inside measurements; liners for this purpose are cast here. For sometime past, forged-steel shoes have been used in preference to the cast-iron shoes of our own make. The steel shoes cost approximately 15 cents per ton of ore crushed, as compared with approximately 18 cents for the cast-iron shoes. We, however, cast all our own dies, for which purpose the worn-out shoes and otherwise useless iron and steel scrap are employed. The average life of the forged-steel shoes is about 95 days, while that of the cast-iron dies is approximately 33 days. All of the cams are equipped with Blanton fasteners, which give good satisfaction. The cam-shafts are $4\frac{5}{8}$ in. in diameter and weigh about 425 pounds. Heavier cam-shafts would be much preferable, but it would prove a difficult matter to bring in a cam-shaft of more than the present weight.

From the batteries, the pulp passes directly over 10 Wilfley concentrators, running with a $\frac{7}{8}$-in. stroke at a speed of 215

strokes per minute. During the year ending July 1, 1904, the concentrators removed 0.76 per cent. by weight of the ore, forming concentrates which contained 18.28 per cent. of the gold- and 17.98 per cent. of the silver-values of the ore crushed during this period.

A large wooden launder conveys the pulp from the tables to the tailings elevator-wheel. The latter is 14 ft. in diameter and is of the outside-bucket type, having 22 steel buckets, each 18 in. long, 8.5 in. wide and 8.5 in. deep, and of a capacity of about 1,025 cu. inches. The wheel is driven by a $\frac{5}{8}$-in. plow-steel wire-cable, at a speed of 18 rev. per minute. The discharge-efficiency, as in all wheels of this type, is not high, the discharged tailings leaving the wheel in a launder 5.5 ft. above the level of the mill-launder supplying the pulp.

A large masonry sand-retaining tank divided into four compartments, each compartment measuring 25 ft. by 80 ft. by 4 ft. in depth, receives the product from the wheel. Distribution is effected by means of a central launder in each compartment, provided with a number of 4-in. side discharge-pipes. Each compartment is provided with a removable end-discharge gate, 4 ft. wide, composed of pieces of 2-in. plank, planed smooth on the edges and sliding in guides secured to the side-posts. As the compartment fills up with sands the discharge of this gates is raised. The discharge-overflow empties into the main slime-launder. Each compartment also communicates with its immediate neighbors by means of small, side-discharge doors. The purpose of this arrangement is that the mill-product may be emptying into one compartment, from which a portion of the finer material escapes through one of the side gates to an adjoining compartment, while the finest material is passing off in the discharge over the lowered end gate of this second compartment.

It is found, however, that a considerable quantity of the finest material will always tend to collect at the lower end of the first compartment receiving the discharge of the elevator-wheel, to lessen which, an overflow from the end gate of this compartment is also necessary. In every case, however, the first 5 or 6 tons of material removed from the compartments are always extremely slimy and are trammed a short distance to an open drying-patio, where they are spread out, sun-dried and broken

up, after which they are mixed in with the coarser sands and treated in the leaching-vats. A third compartment of the sands-retaining tank is kept full of sands, which are being allowed to drain, while the dry sands are being trammed from the fourth compartment. Each of these compartments holds the sands of from 48 to 60 hr.' crushing in the mill when operating under normal conditions. The retained sands are usually subjected to about 2 days' draining before commencing to charge them into the leaching-vats. The very fine material escaping in the overflow from the masonry retaining-tank is carried by means of a wooden launder to three, so-called, slime-pits having an aggregate capacity of approximately 15,000 tons. Every precaution is exercised that no slimes escape at the overflow-gates of these pits, but, as is to be expected, at no time is such overflow perfectly clear and free from suspended matter.

During the 18 months ending Dec. 31, 1904, of the total net tonnage crushed in the mill, 19.16 per cent. went to the slime-pits. Various sizing-tests, using the ordinary brass-wire assayer-screens, have shown that, on an average, about 6 per cent. of this material is retained on 100-mesh, while approximately 85 per cent. passes a 200-mesh screen.

Although this material as a whole is chiefly slimes, which on long drying crack up into layers almost absolutely impervious to leaching, it is found that considerable quantities of extremely fine, but leachable, sands are deposited at the heads of the slime-pits in the vicinity of the discharges from the slime-launder. About two months after ceasing to discharge into any one slime-pit, this very fine sandy material at the heads of the pits will have dried sufficiently during ordinarily dry weather to permit of being walked on, and it is then conveyed by contract labor to the open drying-floor or patio, together with a certain percentage of more slimy material which unavoidably becomes mixed with it. Here the material is spread out, sun-dried and thoroughly broken up, after which it is mixed in with the ordinary sands and treated by leaching.

During the past year 2,400 tons of very fine material from the slime-pits have been treated in this manner. By far the greater portion of the material collected in the slime-pits, however, is so extremely fine and of such a clayey nature that, as above stated, it is almost absolutely impervious to leaching.

This portion, which we term "slimes," is allowed to dry as much as practicable, and is then treated by agitation in a separate plant, as will be described further on in this paper.

Figs. 2 and 3 show the arrangement of the cyanide leaching-plant in plan and in elevation.

Cyanide Treatment of Sands.

The sands retained in the compartments of the large masonry sand-retaining tank, after being allowed to drain as long as possible, usually from 36 to 48 hr., are trammed by half-ton cars to the cyanide leaching-vats, 12 in number, and each 30 ft. in diameter and 4.5 ft. deep. The filter-bottom, which reduces the available depth to 4 ft. 2 in., consists of a wooden, lattice-framework covered by a layer of cocoa-matting, over which is stretched a filter-cloth of 8-oz. duck. Two heavier grades of duck have been tried as filter-cloths, but it was found that they tended to reduce the rate of leaching and gave less satisfactory service than the 8-oz. cloth; 10 of the leaching-vats are constructed of No. 9 sheet-steel; the other two were built here on the premises and are made of 3-in. native pine. Two additional vats of the same dimensions and capacity, made of 3-in. redwood throughout, are now in course of erection.

The sands, as charged into the leaching-vats, carry from 14 to 16 per cent. of moisture; and each vat is charged with the equivalent of 100 tons of dry sands. On the way to the leaching-vats, slaked lime is added to each car-load, usually in the proportion of from 4 to 5 lb. of lime per ton.

The vats are filled and discharged by contract for $19 a vat, which is equivalent to 19 cents per ton.

Two strengths of stock-solutions are employed: the weak solution averaging between 0.25 and 0.30 per cent. of KCN, and the strong solution averaging from 0.75 to 0.80 per cent. of KCN. The working-strength of the solutions is always taken as that indicated by titration with silver nitrate in presence of a few drops of a 10-per cent. solution of potassium iodide, as an indicator; 10 c.c. of the cyanide solution being taken for titration. For the sake of convenience, we still express the strength of our working-solutions in terms of potassium cyanide, although for over a year past we have been employing sodium cyanide exclusively. Titration with silver

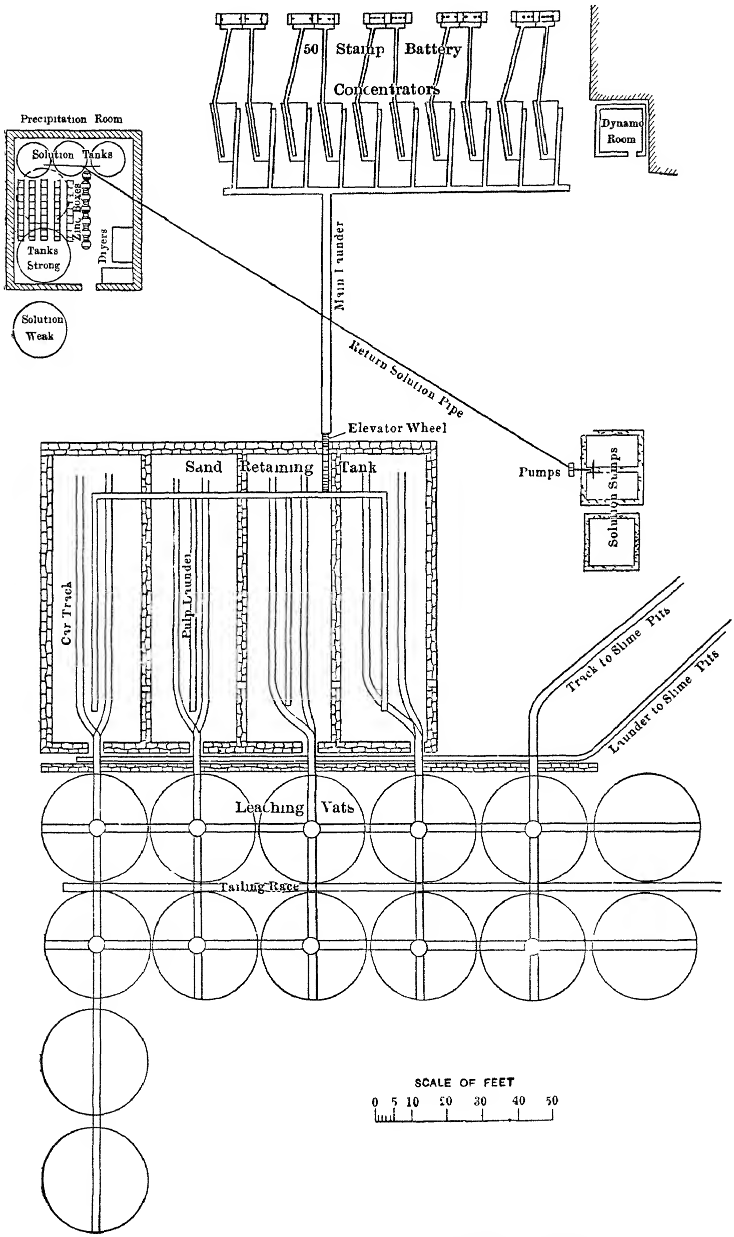


FIG. 2.—CYANIDE LEACHING-PLANT; PLAN.

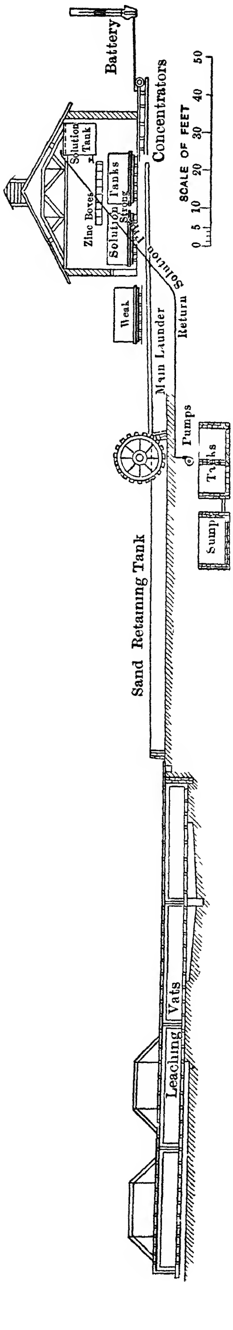


Fig. 3.—Cyanide Leaching-Plant; Elevation.

nitrate shows that the sodium cyanide being used is, on an average, equivalent to about 125 per cent. of potassium cyanide. Our experience at this place with sodium cyanide leads us to believe that it is fully as efficient as potassium cyanide for the dissolution of the values contained in the ore. It also appears that, since commencing the exclusive use of sodium cyanide, our solutions become rather less fouled than was previously the case. Freighting-expenses are always a considerable item with us, and by the adoption of sodium cyanide (equivalent, as above stated, to 125 per cent. of potassium cyanide) a saving of 20 per cent. of the freighting-expenses on this article has been effected. Assuming, as our experience seems to confirm, that sodium cyanide is as efficient as potassium cyanide, we may reasonably expect that it will gradually displace the latter, which, until recently, has been almost universally employed. Besides the direct saving in transportation-expenses, the sodium cyanide appears to possess other advantages. From a metallurgical standpoint,other things being equal, it seems more preferable to use a salt as nearly pure as can be obtained. Absolutely pure sodium cyanide being equivalent to about 132 per cent. of potassium cyanide, a product testing from 125 to 130 per cent. of potassium cyanide is manifestly nearly pure. It by no means follows, however, that the ordinary commercial cyanide, rated as 98 or 99 per cent. pure, and which by

the usual silver nitrate titration will stand up to this strength, contains but 1 to 2 per cent. of impurities. That this commercial cyanide frequently carries a varying percentage of sodium cyanide is a well-known fact, and it of course naturally follows, on account of the relatively greater proportion of the CN radical contained in this salt as compared with potassium cyanide, that the greater this percentage of sodium cyanide contained in the ordinary 98 to 99 per cent. of potassium cyanide the greater also will be the percentage of impurities present.

As soon as a vat is charged, from 20 to 25 tons of weak solution, carrying, as just stated, from 0.25 to 0.30 per cent. of KCN, is introduced from the bottom by means of a 2-in. drop-pipe, terminating in a "T" underneath the filter. This solution is introduced slowly in order to avoid channeling the charge, and it usually makes its appearance on top of the sands about 6 or 7 hr. after being turned on. When the solution stands 2 or 3 in. above the top of the charge, it is turned off, and the charge is allowed to soak for 6 hr., during which time the material will usually have settled from 3 to 4 inches. The weak-solution discharge-valve at the bottom of the vat is now opened and leaching is commenced. During the next two days, or sometimes three, weak solution is added from the top, as rapidly as permitted by the leaching-rate of the charge, until a total of from 100 to 130 tons has been applied. From 60 to 70 tons of strong solution, averaging between 0.75 and 0.80 per cent. of KCN, is now run through the charge at a somewhat slower rate, the usual time consumed for this operation being about 48 hours. Weak solution is now run through the charge as rapidly as possible, until within about 24 hr. before the time it is to be discharged, when wash-water to the amount of from 15 to 20 tons is added in lots of about 5 tons each. The residue is now ready for sluicing, which is accomplished by two men in about 6 hr., each using a 2-in. hose, equipped with a 0.5-in. nozzle and operating under a head of 72 feet. After finishing the sluicing-out, the canvas filter is usually swept clean with a broom, it being found that if this is not done, the filter-cloth frequently tends to become clogged with very fine slimes, which lowers the rate of filtration. Each vat is equipped with two 10-in. by 10-in. square bottom-discharge doors.

The quantity of wash-water used is regulated principally by the balance of the solutions on hand. Although a separate zinc-box is provided for waste solutions, it is very seldom used except during the rainy season, since very rarely during other times of the year is any solution run to waste. Only two of the leaching-vats are under cover, and during the rainy season it frequently becomes necessary to run a certain percentage of the solution to waste, as during each heavy rain the exposed vats collect a very appreciable quantity of water.

It has so far been my experience, that as thorough oxygenation as possible of the material being treated is a very desirable feature in the cyanidation of most gold-ores, and, in the case of the Palmarejo ores, it appears to be absolutely essential in order to obtain the best results. Due to the fact that the major portion of the value of the material being treated is in the silver-content, the actual weight of fine metal to be acted upon is much greater than is ordinarily the case with gold-ores.

In order to permit of as much air being supplied to the sands as possible, the solution during the treatment is frequently allowed to drain down several inches beneath the surface of the charge, air being thus allowed to penetrate the material to this depth. It is our custom to assay each charge every 24 hr., after the first 5 days of treatment. Before each sampling, the solution is usually allowed to drain down to several inches below the surface of the sands, thus allowing additional opportunity for the entrance of air into the upper layer of the charge.

Under the most favorable conditions, however, the air drawn into the top layer of the charge can have but little effect on the lower half. It is doubtless due, at least largely, to this difference in aëration to which the upper and lower portions of the charge are subjected, that practically without exception, when ready for discharging, the lower half of the charge will run from 1 to 2 oz. of silver higher than the upper half. Frequently this difference is even more marked, and occasionally a difference of as much as 3 or 4 oz. will be obtained between the upper 12 in. and the bottom 12 in. of the charge.

To overcome this difficulty to a certain extent, after many experiments, the practice was adopted sometime ago of transferring as many charges as possible from one vat to another during the treatment. To transfer a vat means the loss of

practically 24 hr. of its available leaching-time, as it is necessary to drain the charge for about 12 hr. before commencing to transfer it. Also, it is necessary that one of the adjoining vats be empty at the proper time to receive the transferred charge. By careful manipulation, at present, about one-third of the total number of charges treated are transferred. When the two additional vats, which are now in course of erection, are completed, a greater number of charges can be transferred and the additional capacity afforded will also permit of a longer treatment to offset the time lost in transferral. The transferring is done by contract for $16 a vat, which is equal to 16 cents per ton. While being transferred the material is of course given a thorough exposure to the air, any existing lumps are broken up by the shoveling, and, roughly speaking, the bottom layer of the original charge becomes the top layer of the transferred charge. The period during the treatment at which the transfer is made naturally depends upon the time at which an adjoining vat is empty and ready to receive the transferred sands, but operations are usually so timed that the transfer takes place while the strong solution is in contact with the material. During the transfer, about 100 lb. of slaked lime are evenly distributed near the bottom of the vat receiving the transferred charge.

The charge is sampled just before and just after transferral, the latter sample being nearly always about 1 oz. higher in silver than the former, a result which is doubtless due to the fact that, in taking a sample, the almost unavoidable tendency is to obtain a larger percentage of the top half of the charge than of the lower half; and, as above mentioned, the lower half of the original charge, after the transferral, becomes practically the upper half of the transferred charge.

The first solution, added after the transfer, is introduced slowly from the bottom, after which the regular routine treatment is continued. The value of the effluent solution from a charge is invariably found to increase immediately after the charge has been transferred, such increase being usually from 2 to 3 oz. of silver per ton of solution.

In general, all heads- and tailings-samples of the sands treated are taken with an 1.5-in. auger at from 12 to 16 different places in the charge.

Table I. gives a part quantitative analyses of two samples, taken some time ago, of the mill-product after concentration and ready for cyaniding. The composition of the sands now being treated will doubtless vary but little from that of these samples.

TABLE I.—*Part Quantitative Analyses of Sands.*

Composition	Sample No 1	Sample No 2
	Per Cent	Per Cent
Insoluble (chiefly SiO_2)	88 40	81.90
Iron	1 20	1.05
Sulphur	Trace	0 17
Manganese	2.37	1.87
Lime	2.88	6.00
Magnesia	0 61	1.38

NOTE.—Qualitative analyses of the ore before concentration shows the presence of small quantities of antimony, arsenic and bismuth, and occasionally traces of zinc and of copper are found

Tables II. and III. give a complete record and analysis of the results obtained on a charge which was transferred during treatment. Although dealing with but a single charge, these results represent those regularly obtained in ordinary operations.

The effluent solution from the leaching-vats is carried to the sump-tanks by means of two separate lines, one for the weak, the other for the strong solution. These tanks are of masonry and are three in number. Two of them, having a combined capacity of 65 tons, are connected together and serve as a weak-solution sump; the other, having a capacity of 25 tons, is used for the strong solution. All solution draining from the leaching-vats is passed through the zinc-boxes before being returned to the tanks.

The proper tonnage of strong solution is maintained by frequently determining the strength of the effluent solution from the leaching-vats, and when this strength reaches about 0.35 per cent. of KCN, the solution is turned into the strong solution-sump. As a working-guide for maintaining the proper alkalinity of stock-solutions, they are titrated every day with the addition of about 5 c.c. of strong lime-water; 10 c.c. of cyanide solution being used in all titrations. If the addition of the lime-water causes a difference of more than 0.5 lb. in the

TABLE II.—*Detailed Record of a Treatment of Sands.*

Charge No. 744. Net tonnage, 100. Moisture, 15.5 per cent. Lime added, 0.25 per cent. Assay-value per ton was $2.68 of gold and 15 90 oz. of silver.

Date	Time	Solution Added Per Cent of KCN			Effluent Solution. Assay-Value			Tailings-Assays		Percentage of Extraction as per Tailings-Assays	
		Tons	Weak	Strong	KCN	Gold	Silver	Gold	Silver	Gold	Silver.
					Per Cent		Ounces		Ounces		
Sept 20	4 30 p m (a)	20	0 27								
Sept 21	5 00 a m	15	0 29		0 08						
	4 00 p m	20	0 22		0 16	$0 66	1 28				
Sept 22	3 00 a m	17	0 23		0 20	0 78	1 49	..		..	..
	2 30 p m	20	0 25		0 21	0 78	1 61				
Sept 23	4 00 a m	20	0 24		0 21	0 78	1 80	$1 03	13 74	$61 57	$13 59
	1 00 p m	15	0 24		0 22	0 82	2 26				
	8 00 p m	15		0 80	0 23						
Sept 24	9 00 a m	15		0 80	0 24	0,87	2 59	0 82	11 26	69 40	29 18
	7 00 p m	17		0 82	0 36	0 82	3 30				
Sept 25	7 00 a m	17		0 78	0 59	0 87	4 05	0 82	10 42	69 40	34 46
	4 00 p m (b)				0 60						
Sept 26	6 00 a m				0 61			0 62	9 47	76 87	40 44
	4 00 p m	20	0 28		0 42			0 62	10 64	76 87	33 08
Sept 27	3 00 a m	18	0 29		0 31	1 51	7 59	0 42	9 96	84 33	37 36
	2 00 p m	16	0 29		0 29						
	11 00 p m	20	0 29		0 28	0,62	5 56				
Sept 28	8 00 a m	15	0 28		0 26	0 0	3 26	0 20	8 38	92 54	47 30
	5 00 p m	15	0 28		0 26						
Sept 29	2 30 a m	15	0 26		0 25			0 10	7 87	96 27	50 50
	1 00 p m	15	0 26		0 25	0 20	2 10				
	11 00 p m	5	Wash-water								
Sept 30	4 00 a m	5	Wash-water		0 20			0 10	7 24	96 27	54 47
	11 00 a m	5	Wash-water		0 18	Tr	1 10				
	7 00 p m (c)		Discharged		0 12			0 10	7 44	96 27	53 21

(a) Turned solution on from bottom at 4.30 p.m. Solution appeared on top at 11 p m. Let soak for six hours. Charge settled 4 inches

(b) Let drain preparatory to transferring At 6 30 a.m , Sept. 26, commenced to transfer to Vat No. 3 Finished transferring 4 p.m. 100 lb. lime distributed near bottom of transferred charge Solution turned on from bottom, appeared on top at 10 p.m.

(c) Started to discharge vat at 7 p.m. Finished discharging at 2 a.m.

NOTE.—Extraction equals 96.27 per cent of gold and 53.21 per cent. of silver.

Total time of treatment, including charging and discharging, 11 days.

Solution added: Weak, 261; strong, 64; wash-water, 15; total, 340 tons.

All tailings-samples with the exception of the discharged tailings were washed before assaying.

During transferral a sample taken from upper 18 in. of charge assayed: $0.50 of gold, 9 20 oz of silver, and one from the lower 18 in. of charge assayed $0.82 of gold and 11 92 oz. of silver.

indicated strength of the solution, the quantity of lime added to the sands charged into the leaching-vats is increased.

From the sumps, the solution is elevated by means of a 3-in. centrifugal pump, running 900 rev. per min., a verticle distance of 29 ft., through a horizontal distance of about 150 ft., to three storage-tanks at the head of the zinc-boxes. These tanks

TABLE III.—*Sizing-Test (A).*

Made on heads from Vat No. 1; Charge No. 744. Sept 21, 1904.
1,000 g. taken. Screens used were the ordinary brass-wire assayers' screens.
Assay-value of material per ton was $2 68 of gold and 15.90 oz. of silver.

Size of Material	Weight	Assay-Value		Percentage of Total Value Contained	
		Gold	Silver.	Gold	Silver.
	Per Cent		Ounces	Per Cent	Per Cent
Retained on 60-mesh. ...	41 2	$2 27	14 78	34 90	38 29
Retained on 80-mesh	10.9	2 16	12 86	8 78	8.82
Retained on 100-mesh. ...	8.2	1 85	12 94	5 66	6.67
Retained on 120-mesh.	11.5	1 85	12 66	7.94	9.16
Retained on 150-mesh ...	2.7	2 68	14.90	2.70	2 53
Passed 150-mesh..	25 5	4.25	21.42	40 44	34.35
Totals	100 0	.. . . .	. ...	100.42	99 82

Sizing-Test (B)

Made on discharged tailings of Charge No. 744 Oct 1, 1904
1,000 g taken. Used same screens as in Test A.
Assay-value of material per ton was $0.10 of gold and 7 44 oz. of silver.

Size of Material	Weight	Assay-Value		Percentage of Total Val Contained		Percentage of Extraction on Sized Product		Constituent Portion of Total Ext	
		Gold	Silver	Gold	Silver	Gold	Silver	Gold	Silver
	Per Cent		Ounces		Per Ct		Per Ct		Per Ct
Retained on 60-mesh	41 8	$0 20	9 43		52 98		36 20		15 13
Retained on 80-mesh	11 0	Tr	5 65		8 35		56 07		6 17
Retained on 100-mesh	8 8	Tr	4 88		5 77		62 28		5 48
Retained on 120-mesh	10 4	Tr	4 57		6 39		63 90		6 64
Retained on 150-mesh	3 1	Tr	4 99		2 08		66 51		2 06
Passed 150-mesh	24 9	0 10	7 10		23 76		66 85		16 65
Totals .	100 0				99 33	..	.		52 13

are each 10 ft. in diameter, 8 ft. deep and have a capacity of 19 tons. Two of these tanks are used for the weak and one for the strong solution. The solution from the vats now passes through the zinc-boxes, from which it is led to three storage-solution tanks beneath the boxes. These storage-tanks are made of No. 9 sheet-steel, each one being 15 ft. in diameter, 6 ft. deep and of a capacity of 33 tons. Two of them are used as strong-solution storage-tanks, the other as a weak-solution storage-tank. The strong solution is brought up to the required strength by adding the necessary quantity of cyanide to the last compartment of the strong-solution zinc-box, which is

reserved for this purpose. No cyanide is ever added directly to the weak solution.

Precipitation of Silver and Gold.

There are six zinc-boxes, five being used for the weak solution and one for the strong solution. The five weak-solution boxes, constructed of No. 10 sheet-steel, are 2 ft. wide and 18 ft. long over all. Each box contains eight compartments, each compartment having an available zinc-capacity of 24 by 24 by 18 in., equivalent to 6 cu. ft. Six compartments only are filled with zinc shavings and each box, when freshly dressed, therefore contains 36 cu. ft. of shavings, making a total of 180 cu. ft. of zinc shavings in the five weak-solution boxes.

The strong-solution zinc-box consists of seven individual, round boxes or compartments, placed in series, each compartment being 28 in. in diameter and 24 in. in depth, and having an available zinc-capacity of approximately 5 cu. feet. Only six of the compartments are filled with shavings, the last compartment being reserved, as above stated, for the addition of the quantity of cyanide required to bring the strong solution up to standard strength. The strong-solution zinc-box has, therefore, a total of 30 cu. ft. of zinc shavings.

Records are kept of the quantity of weak and strong solution daily passing through the boxes, together with their assay-values before and after precipitation. These records for the year (1904) show that 91,793 tons of weak and 22,251 tons of strong solution passed through the boxes, which is equivalent to an average of 251 tons of weak and 61 tons of strong solution every 24 hours. During the period under review, the flow of the solution through the boxes was occasionally interrupted for a short time, due to the ordinary clean-ups, dressing of the boxes, etc., as well as on account of various minor and unavoidable delays. Without taking such stoppages into account, however, the average rate of flow of the solution through the boxes equaled 1.4 tons of weak solution per 24 hr. per cu. ft. of shavings, and 2.03 tons of strong solution per 24 hr. per cu. ft. of shavings.

The actual rate of flow, however, exceeds these figures, as it is here assumed that the boxes were at all times kept dressed

with the maximum amount of shavings, which, strictly speaking, was seldom the case.

The shavings used are cut on an ordinary zinc-lathe, from No. 9 sheet-zinc; the size of the sheets being 18 by 84 inches. Ordinarily, six sheets are wound on the mandrel of the lathe for one cutting. One boy, working 12 hr., cuts a sufficient quantity of shavings to supply both the leaching- and agitation-plants, which together require an average of about 120 lb. of shavings per 24 hours.

It is found best to keep only a few day's shavings on hand, freshly-cut shavings giving better results than those which have been cut for some time. The customary practice of moving the zinc from the lower to the upper compartments, when dressing the boxes, is not followed; fresh zinc being added as required to the top of each compartment.

The strength of the solution running through the weak-solution boxes averages between 0.25 and 0.30 per cent. of KCN, while that of the solution going to the strong zinc-box averages between 0.35 and 0.45 per cent. of KCN.

The average assay-values per ton of the solutions entering the zinc-boxes, was approximately as follows:—

Weak Solution	Strong Solution
$1 of gold and 2.25 oz. of silver	$1.24 of gold and 3 5 oz. of silver.

It is very seldom that any trouble is experienced with the precipitation of the contained values. As a rule, the precipitation of the gold is practically perfect, while that of the silver averages about 95 per cent. When the percentage of precipitation falls off, it is usually due to the presence of an accumulated excess of lime in the solution.

Table IV. gives the results of assays taken from each compartment of both the weak-solution and the strong-solution boxes, and shows the progress of precipitation in the successive compartments. These results may be taken as an average of those regularly obtained.

Clean-up of Zinc-Boxes.

On account of structural difficulties, the clean-up facilities are not as convenient as could be desired and it is necessary to handle the precipitates more than would otherwise be the case.

TABLE IV.—*Precipitation of Gold and Silver in Zinc-Boxes.*

A. WEAK SOLUTION ZINC-BOX.

Compartment.	Assay-Value of Solution.		Extraction		Constituent Portion of Total Ext		Strength of Solution. Quantity of KCN per Ton.	
	Gold.	Silver	Gold	Silver	Gold	Silver.	Without Lime	Addition of 5 c c. Strong Lime-Water
		Ounces	Per Cent	Per Cent	Per Cent	Per Cent	Pounds	Pounds
Entering No. 1	$1 03	2.46	....	. .	...	..	6 3	6.6
Leaving No 1..	0 82	1.89	20 39	23 17	20 39	23 17	6.3	6 6
Leaving No 2	0.56	1.02	45 63	58 54	25 24	35.37	6 4	6 7
Leaving No. 3.	0 41	0 74	60.19	69 92	14 56	11 38	6.4	6 7
Leaving No. 4	0 20	0 36	80 58	85 37	20 39	15 45	6 3	6 7
Leaving No. 5	0 10	0 28	90 30	88 66	9.72	3 29	6 4	6 6
Leaving No 6..	trace	0.16	100 00	93.50	9 70	4 84	6.4	6.7
....	.	....	....	...	100 00	93 50	....	....

B STRONG SOLUTION ZINC-BOX

Compartment	Assay-Value of Solution		Extraction		Constituent Portion of Total Ext		Strength of Solution Quantity of KCN per Ton	
	Gold	Silver	Gold	Silver	Gold	Silver	Without Lime	Addition of 5 c c. Strong Lime-Water
		Ounces	Per Cent	Per Cent	Per Cent	Per Cent	Pounds	Pounds
Entering No. 1 .	$1.24	3.64	..... .		....	.... .	8 4	9.0
Leaving No. 1..	1 03	3.18	16 94	12 64	16 94	12 64	8 4	9.1
Leaving No 2	0 51	1.74	58 87	52 20	41 93	39 56	8 5	9.1
Leaving No. 3..	0 41	1 03	66 94	71.70	8 07	19.50	8 5	9.2
Leaving No. 4..	0 20	0 71	83 87	80 49	16.93	8 79	8 6	9.3
Leaving No. 5.	0 10	0.42	91 94	88 46	8 07	7 97	8 6	9.4
Leaving No. 6 .	trace	0.18	100 00	95 05	8 06	6 59	8 6	9.4
....	....	. ...	. ...	. . .	100.00	95 05	....	.. . .

All the boxes are cleaned up twice a month. Before commencing on any one box, clear water is passed through it a sufficient length of time to displace most of the cyanide solution, which usually requires 10 or 15 minutes. The shavings in the first compartment are thoroughly washed, after which they are removed and the water bailed out into the next compartment. The precipitates are now conveyed by means of buckets to the clean-up box, where they are passed through a 20-mesh screen. A small percentage of "short" zinc passes through this screen, but the greater part of such product is here separated from the finer

precipitates and is returned to the boxes. The first compartment is now filled with water and the zinc contained in the other compartments is gradually transferred to it and thoroughly washed, the precipitates from each compartment being carried to the clean-up box as before mentioned. In order to reduce to a minimum the rapid oxidizing effect resulting from exposure of the wet zinc to the atmosphere, the washed shavings are at once placed in the highest vacant compartment of the zinc-box and covered with solution.

The precipitates accumulating in the first compartment from the washing of the shavings, after being allowed to settle for a short time, are also removed to the clean-up box. This latter is provided with three smaller settling-boxes, placed in series, which take the overflow from it. The bottom of the clean-up box is tapped by a 4-in. drop-pipe, which discharges directly into two large drying-pans beneath.

The product is now dried as much as is practicable, and then mixed, carefully sampled, assayed and sold on the premises to one of the large ore-buying companies.

The moisture contained in the dried precipitates has averaged 0.27 per cent. during the past year.

The clean-ups, as would naturally be supposed, are quite bulky; the net, dry weight of precipitates in each clean-up averaged between 1,100 and 1,200 lb. avoirdupois during the past year.

Considering the fact that the precipitates receive no treatment whatever beyond being passed through a 20-mesh screen and the simple drying as above mentioned, it is rather surprising that they carry such a comparatively high percentage of fine metal. During 1904, the assay-returns, on which the sale of the precipitates is based, have averaged slightly over 20,000 oz. of silver and approximately $8,000 of gold per short ton. By actual weight, therefore, the percentage of fine metal contained in the dried product recovered throughout this period was approximately 68.57 per cent. of silver and 1.33 per cent. of gold, making a total of 69.90 per cent. of both metals.

To the best of my knowledge, this is the highest percentage of precious metal contained in any cyanide-precipitates regularly obtained in ordinary zinc-precipitation.

Two clean-ups during 1904, of a combined net weight slightly

exceeding 2,300 lb., gave an average assay-value of 22,200 oz. of silver per ton, making the fine silver-content equal to 76.12 per cent. by weight of the precipitates.

Having noticed in recent papers of the Institute[1] the discussion of the number of ounces of fine metal handled per man-hour while removing the precipitates from the zinc-boxes or filter-presses, the following data is offered.

A record, kept for some time, of the labor employed in clean-ups, shows that on an average four men (one American and three native helpers) would readily remove 1,200 lb. (net dry weight) of precipitates from the boxes and have the product in the drying-pans in 8 hours. Based on the average assays of the precipitates for the year, this means that, in 32 man-hours, approximately 12,200 oz. of fine metal could be handled, being equivalent to a duty of 381 oz. per man-hour. This rather high duty is of course due entirely to the fact that the precipitates contain such an exceptionally high percentage of precious metals.

Table V. gives the result of a sizing-test made on one lot of precipitates, which ran somewhat lower than the average in silver.

TABLE V.—*Sizing-Test of Cyanide Precipitates.*

Assay-value of precipitates, per ton, was $8,622 90 of gold and 19,488.65 oz. of silver.

Size of Material	Weight	Assay-Value.	
		Gold	Silver
	Per Cent		Ounces
Retained on 80 mesh	11 13	$1,914 04	2,805 40
Retained on 100-mesh	2 41	3,369.21	5,565 25
Retained on 150-mesh	3 90	5,465 00	11,128 80
Retained on 200-mesh	1 39	5,702.25	12,274.24
Passed 200-mesh	81.17	9,683.00	22,726.80
	100 00	..	.

Tonnage and Extraction Percentages.

During 1904, a total of 34,900 tons of sands were treated in the leaching-plant. This tonnage would have been considerably greater had it not been that during this period, aside from

[1] *Trans.*, xxxiv , 983–984.

the ordinary stoppages in the mill due to general necessary repairs, the mill was closed down at different times, for intervals aggregating a total of 57 days for the entire 50-stamps, from causes beyond our control, such as shortage of water-power during the dry season, wash-outs along the railroad and power-ditch during the heavy rains, etc.

The extraction for 1904, indicated by the assay-differences between the sands charged into the leaching-vats and being discharged, was 95.5 per cent. of the gold- and 52 5 per cent. of the silver-values. The combined total value of the precipitates recovered during the year checks closely with that called for by the sand-assays.

The assay-values of the sands treated during this period has averaged approximately $2.85 of gold and slightly more than 16 oz. of silver per ton.

The total returns called for by the zinc-box precipitation-records correspond very closely to the actual returns from the precipitates recovered. During 1904, the returns from the precipitates were practically 1 per cent. less in gold and 0.5 per cent. more in silver than those called for by the precipitation-records.

This difference in the gold is accounted for by the fact that the precipitated solutions are only occasionally assayed for gold, it being ordinarily assumed in the daily precipitation-records, that the precipitation of the gold is perfect, while, as a matter of fact, the solution leaving the zinc-boxes will very probably carry an average of a few cents of gold per ton.

Consumption of Cyanide, Zinc and Lime.

The office-records show, that for 1904, the consumption per ton of sands cyanided was as follows:—cyanide, 2.95; zinc, 0.96; and lime, 4.33 pounds.

It will be remembered in this connection that, during this period, sodium cyanide of a strength equivalent to 125 per cent. of potassium cyanide was exclusively employed. Expressed in terms of potassium cyanide, this consumption would therefore equal 3.69 lb. of potassium cyanide per ton of ore treated.

General Remarks.

The total quantity of solution passing through the zinc-boxes during 1904, divided by the quantity of sands for the same period, shows that, for each ton of sands treated, 3.27 tons of solution left the leaching-vats, of which 2.63 tons were weak solution and 0.64 tons strong solution.

It is found in the treatment, that large quantities of the weaker solution give more satisfactory results than small quantities of the strong solution, and it is always made an important point to pass as much weak solution through a charge as possible. Experience has demonstrated that, in a given length of treatment, a rapid leaching-rate and a large quantity of solution is more efficient than a slower leaching-rate and a consequently lesser quantity of solution. The solution pipe-lines and launders occasionally become quite choked in places with scale deposited from the solution. This scale, taken from lines carrying precipitated solution, contained from a trace to $1 of gold and from 1 to 7 or 8 oz. of silver per ton. The scale deposited from the unprecipitated solution usually runs higher, several assays taken having averaged about $5 of gold and 18 oz. of silver per ton.

Ordinarily the solutions do not become excessively fouled. They usually contain small percentages of iron and manganese in addition to the zinc compounds present. Alkaline sulphides are very rarely or never noticed in solution. Sulphocyanides and ferrocyanides appear to be constantly present, however, in fair quantities. The average of a number of determinations made at various times gives about 0.41 per cent. of ferrocyanides and 0.048 per cent. of sulphocyanides.

The sands charged averaged about 0.09 per cent. of latent acidity, and, as a rule, they contain no free acid.

The concentrates produced are sold to the same company that buys the cyanide-precipitates. When making the original cyanide experiments on this ore, a good deal of time was devoted to an attempt to treat the concentrates by cyanide, but without success. Experiments on both raw and dead-roasted concentrates reduced to various degrees of fineness, by leaching and agitation, for varying periods of time, up to 34 days, and using solutions varying from 0.2 to 2 per cent. of KCN, proved entirely unsatisfactory.

Table VI. gives the working-costs for milling and cyaniding during 1904. It should be remembered that the cost of all supplies is considerably increased by the very heavy freight-transportation expenses, as well as by the duties placed by the Mexican Government on most of the supplies used. The freighting-facilities have not improved any since the change in the milling-operations, the difficulties of transportation remaining as described earlier in this paper, and being, therefore, the source of an unusually heavy portion of the expenses for supplies.

TABLE VI.—*Working-Costs per Ton.*

MILLING:	
Supplies,	$0.640
Labor,	0.357
Lubricating,	0.023
Assay-office (labor and supplies),	0 035
Concentrating,	0.092
Power (ditch, maintenance and supplies),	0 234
Salaries,	0.264
Miscellaneous (lighting, etc.),	0.018
Management and general expenses,	0.336
Total,	$1.999

NOTE.—$1.999 Mexican currency during this period was equivalent to $0 95 gold.

CYANIDING:	
Cyanide (2 95 lb. @ $0.63),	$1 859
Zinc (0 96 lb. @ $0 30),	0.288
Lime (4 33 lb @ $0 0118),	0.051
Other supplies,	0.050
Labor,	0.329
Salaries,	0 371
Assay-office (labor and supplies),	0.036
Power (ditch, maintenance and supplies),	0.017
Miscellaneous (lighting, etc),	0.004
Management and general expenses,	0 186
Total,	$3.191

NOTE.—$3.191 Mexican currency during this period was equivalent to $1.52 gold.

The cost of realization on cyanide-precipitates has not been included in above cyanide working-costs. This cost is naturally very high, the quantity of precipitates produced being much greater in proportion than that produced when treating

gold-ore only, while the treatment-charges per ton of ore are no less. Transportation-expenses on the precipitates are also very heavy. In addition to this comes the heavy item of Government bullion taxes.

The average cost of realization on cyanide-precipitates, per ton of ore cyanided, is as follows:—Government taxes, $0.84; treatment charges (including transportation-expenses), 1.06; total, $1.90.

The cost of realization on the concentrates produced is also unusually high on account of the heavy transportation expenses and Government bullion taxes. The average cost of realization per ton of ore crushed is as follows:—Government taxes, $0.35; treatment charges (including transportation-expenses), 1.08; total, $1.43.

Treatment of Slimes.

As before mentioned, the accumulated and currently produced slimes are now being treated in a separate plant by a system of agitation and decantation, centrifugal pumps being used as the means of agitation. The slime-plant consists essentially of the following parts and accessories:—

Four agitation- and four decantation-vats, all provided with conical bottoms and each being connected with its own separate centrifugal pump; two solution-tanks placed at the head of the zinc-boxes, which receive the solution from the decantation-vats; four sets of zinc-boxes and three solution-sumps, which receive the solution leaving the zinc-boxes; one special solution-tank placed at a higher level than the rest of the plant and used principally to supply solution to the pump-bearings under pressure; two ordinary 3-in. centrifugal pumps, used only for pumping solution from the sumps to any desired vat or to the upper solution-tank just mentioned, they being so connected up that either pump can be used should the other get out of order. Each pump is run by a friction-clutch pulley, which enables it to be started or stopped in a moment, independently of the other pumps. A small 14- by 15-in. friction-geared hoist is used to convey the slimes from the slime-pits to the agitation-vats. The entire plant is run by a 5-ft. Pelton wheel, making about 115 rev. per min., and operating under a head of 81 ft., using a 4-in. nozzle. Water-power is obtained by means of a 14-in. riveted steel-pipe, tapping the main pipe-

line supplying power to the mill. This 14-in. pipe-line, riveted in 10-ft. lengths, was brought in by mule-back, although some difficulty was experienced in its transportation.

Figs. 4 and 5 give plan and section of the slime-plant.

The method of treating the slimes is quite similar to that ordinarily practiced by agitation and decantation, and consists briefly in giving the slimes about a 2 days' agitation in the agitation-vats, with from two to three times their weight of cyanide solution, followed by another 2 (or sometimes 3) days' treatment in the decantation-vats, during which latter portion of the treatment, the charge, after having been sufficiently agitated with the addition of slaked lime, is allowed to settle as much as practicable and the supernatant clear liquor is decanted and passed through the zinc-boxes. This operation of agitation, settling and decantation of clear solution is repeated as many times as permissible, within the time-limit of the treatment, ordinarily being but three or four decantations.

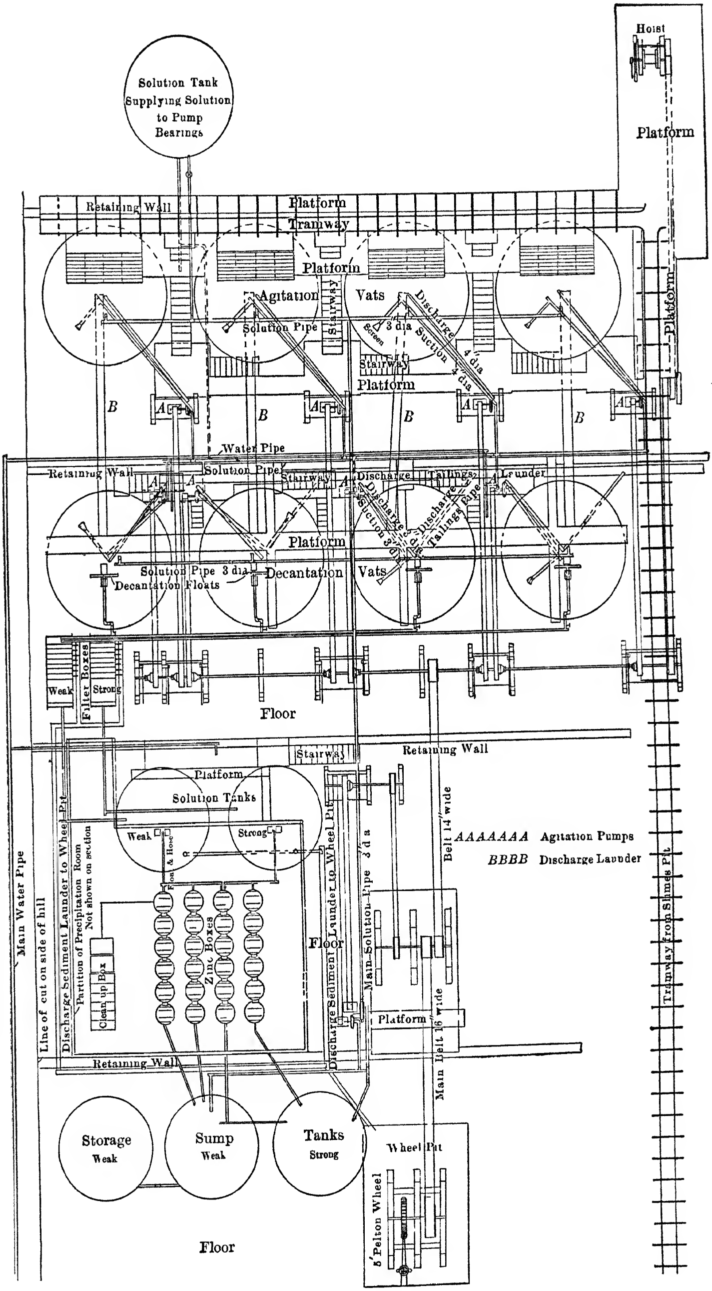
The material under treatment, when dried to from 20 to 25 per cent. of moisture, is quite tough and of the consistency of soft putty. It contains, however, a certain percentage of very fine sands and, when viewed in vertical section, presents a somewhat stratified appearance. As previously mentioned, it cracks, on long drying, into layers almost absolutely impervious to leaching.

The results of the sizing-test given in Table VII. represents an average of those obtained from the material treated up to the present time.

TABLE VII.—*Sizing-Test on Slimes.*

Assay-value of material was $4 13 of gold and 20.30 oz of silver per ton

Size of Material	Weight	Assay-Value		Percentage of Total Values Contained	
		Gold	Silver	Gold	Silver
	Per Cent		Ounces	Per Cent	Per Cent
Retained on 80-mesh..	1 1	$2 38	14 22	0 63	0 77
Retained on 100-mesh.	2.7	2 06	13 60	1 35	1 81
Retained on 120-mesh . .	5 6	1 96	13 02	2 66	3 59
Retained on 150-mesh.	3 1	2 27	14 14	1 70	2 16
Retained on 200-mesh. ...	2 7	2 16	13 10	1.41	1.74
Passed 200-mesh	84 8	4 54	21 68	93.22	90.52
Totals.................. .	100 0	.	..	100 97	100.59



PLAN

FIG 4 —SLIME-PLANT AT THE PALMAREJO MINE, PLAN.

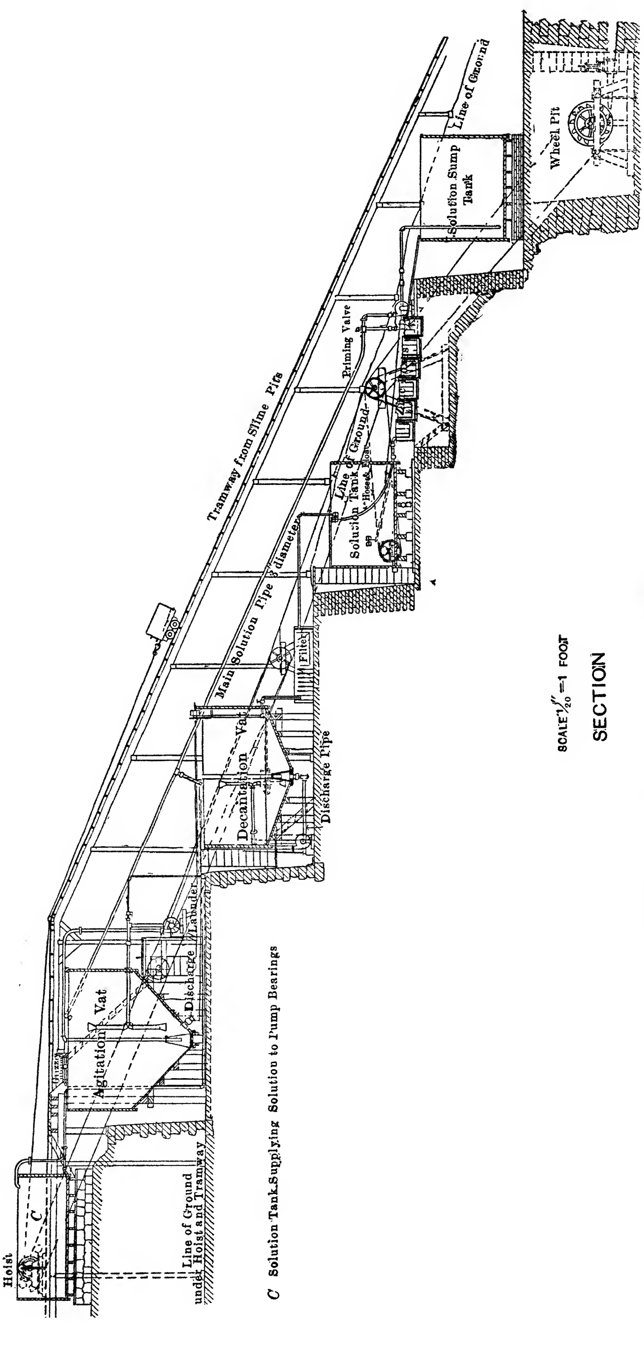


FIG. 5.—SLIME-PLANT AT THE PALMAREJO MINE; LONGITUDINAL SECTION.

Description of the Slime-Plant.

The four agitation-vats made of 3-in. redwood throughout are provided with conical bottoms, slanting at 45 degrees. As shown in Fig. 6, each vat has an inside diameter of 15 ft. 7 in. and their vertical depth from top of side staves to the iron casting at point of conical bottom is 14 ft., the inside depth of vertical side staves being 7 feet 3 inches. Each agitation-vat is connected with a special manganese-steel lined, 4-in. centrifugal pump, which runs at a speed of 900 rev. per minute. The pump is connected with the vat by the 4-in. suction-pipe, *a*,

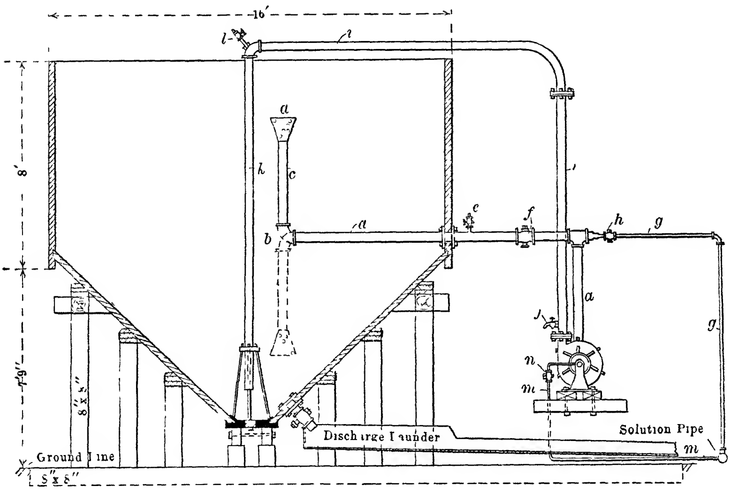


FIG. 6.—AGITATION-VAT AND PUMP CONNECTIONS.

which enters the vat through the side staves about 6 in. above their juncture with the bottom staves and extends nearly to the center of the vat, where it is connected by means of a movable elbow, *b*, with a short piece of 4-in. pipe, *c*, provided at the free end with a good-sized screen or strainer, *d*, made of $\frac{1}{8}$-in. sheet-iron, punched with a number of 1-in. holes; this short piece of pipe, together with the screen, is of such a length that when being lowered the screen will just clear the bottom staves. The screen is provided with a small iron ring, to which is fastened a piece of rope, by means of which it can be raised and lowered.

Just outside the vat, the suction-pipe is provided with an air-cock, *e*, which admits air to the material going through the pump. This air-cock, however, is very rarely used at the present time. The service-cock, *f*, permits the shutting-off of the material from the pump at any time it may become necessary: as, for instance, to repack the stuffing-box or to examine the interior of the pump. The 2-in. pipe-line, *g*, provided with the valve, *h*, connects with the upper solution-tank.

When it becomes necessary to shut the pump down for any length of time, either at the conclusion of the agitation of the charge or at any time during the treatment, the 2-in. valve, *h*, is opened and the service-cock, *f*, is closed, thus allowing clear solution only to pass through the pump. The friction-clutch pulley running the pump is now thrown out of clutch, and after the pump has stopped the valve, *h*, is closed. This arrangement serves to prevent the accumulation in the interior of the pump, when it is stopped for any considerable length of time, of solid matter from the slimy material passing through it.

The 4-in. discharge-pipe, *i*, of the pump is provided with a small bibb-nosed pet-cock, *j*, a few inches from the body of the pump, by means of which samples of the material passing through the pump can readily be taken. The discharge-pipe passes over the top of the vat, and at a point vertically over the center of bottom casting, it is provided with an elbow and drop-pipe, *k*, which reaches to within about 15 in. of the bottom casting. This pipe is held firmly in position by means of an iron clamp and four legs made of $\frac{3}{4}$-in. bolts fastened to the bottom casting and which serve as a tripod. The distance of the lower end of this discharge-pipe from the bottom of vat is a matter of some importance in the agitation; and a number of experiments made along this line have indicated that the best satisfaction is obtained at a distance of 15 in. from the bottom casting.

Different shapes of discharge-ends, or nozzles, have been tried at the lower end of the drop-pipe, but experience so far has shown that the plain 4-in. pipe-end gives as satisfactory results as any other shape. The discharge-pipe of the pump tends to act as a siphon when the pump is stopped at any time during the agitation, and would therefore cause inconvenience when repacking the stuffing-box or making any necessary repairs.

To prevent this, air is admitted to the pipe by opening the small air-cock, *l*, tapped into the elbow at the upper end of the drop-pipe. This air-cock, *l*, is also frequently used to allow the entrance of air into the charge being agitated, it being found more preferable for this purpose than the air-cock on the suction-pipe. (It might be supposed that when this air-cock is open during the agitation, a steady stream of the material passing through the discharge-pipe would be ejected through it; and with regard to the air-cocks similarly situated on the pump-connections of the decantation-vats, such is the case. As regards the pumps connected with the agitation-vats, however, the effect is found to be quite the reverse, and rather a strong air-suction usually occurs when this air-cock is open.)

The pump-bearing nearest the pump-shell is tapped with a small pipe-line, *m*, provided with the valve, *n*, which connects with the upper solution-tank previously mentioned. By this means, the bearing is supplied with clear solution under pressure and the wear on the shaft and bearing is greatly reduced. At the commencement of operations, clear water was supplied to the pump-bearings and was also used for cleaning out the pumps and for priming, when necessary. It was soon found, however, that the quantity of water added in this way increased the volume of stock-solution very appreciably, and, of course, an equal quantity of weak cyanide-solution had ultimately to be run to waste. Not only did this cause an unnecessary mechanical consumption of cyanide, but the quantity of water added through the pump-bearings naturally reduced the strength of the working-solution in the vat under operation, with a consequent deleterious effect on the percentage of extraction. The quantity of solution that will be added to a vat during the usual period of agitation (from 40 to 44 hr.), when the shaft and bearing is a little worn, is surprising, amounting in some cases to 15 tons, even when the greatest care is exercised. The amount of solution added in this way is naturally the least just after the pump has been equipped with a new shaft and new liners, and the bearing re-babbitted. On an average, however, the quantity of solution added to each charge through the pump-bearings is from 5 to 6 tons. The agitation-pumps in use, while in most respects proving very satisfactory, have nevertheless certain defects in their design, which contribute

largely to the rapid wearing of the shaft and the bearing next to the pump-shell, and also to the wearing of the interior, renewable, manganese-steel wearing-parts. The life of these parts naturally varies somewhat, but ordinarily it becomes necessary to equip a pump with a new shaft and certain portions of the manganese-steel wearing-parts and to re-babbit the bearing, about every six weeks. The pumps are equipped with a pulley having a 6-in. face, but it is found preferable to use a 4-in. belt, since this reduces the weight on the pump-shaft with a consequent decrease in its wear, while a 4-in. belt runs the pump equally as well as a 6-in. one. Wire lacing is used on all the belts.

Each agitation-vat was originally provided with a 6-in. discharge-opening at the center of the bottom casting. This opening was bushed down to 4 in. and was provided with a nipple and a straightway valve. The first few vats were discharged from the bottom by this means, but a great deal of trouble was experienced, due to the fact that though all the slimes entering the agitation-vats were passed through a grizzly having 1.25-in. openings, the bottom valve would frequently become choked with small rocks and other solid material which seemed to become unavoidably mixed in with the first slime treated. This bottom discharge was therefore discontinued and a hole was bored in the bottom staves, about 10 in. from the bottom casting, and a 3.5-in. iron service-cock was secured to the vat by means of a short nipple and iron flanges. The vats are discharged through this valve into a wooden launder which conveys the material to the corresponding decantation-vat. This launder is provided with rows of 6-in. wire nails which serve to remove any small pebbles or other foreign matter.

The four decantation-vats, made of 3-in. redwood throughout, are of the same dimensions as the agitation-vats, with the exception that they are provided with conical bottoms, slanting at 20 degrees. Each one is connected with an ordinary 3-in. centrifugal pump. Fig. 7 shows in detail the connection of the pump with the vat, which is practically identical with that of the agitation-vats and pumps. The vat is discharged through a 3.5-in. bottom-discharge valve and pipe, into the residue-launder, from which the discharged material flows to the river. Removal of the clear solution is effected by means of a 2-in. de-

cantation-pipe and float. This pipe enters the side of the vat about 6 in. above the bottom staves and is provided with two loosely-threaded elbows, which permit of the free raising and lowering of the portion within the vat. The float proper is made of two ordinary 5-gal. oil-cans, soldered water-tight and painted with paraffine paint. The rate of decantation is controlled by means of the 2-in. valve just outside of the vat.

It frequently happens that the solution drawn from the decantation-vats is not perfectly clear; and two filter-boxes are therefore provided (see Figs. 4 and 5) for its clarification, at least in part, before it enters the solution-tanks at the head of the zinc-boxes. Each compartment of these filter-boxes is provided with a discharge-valve, by means of which the sediment

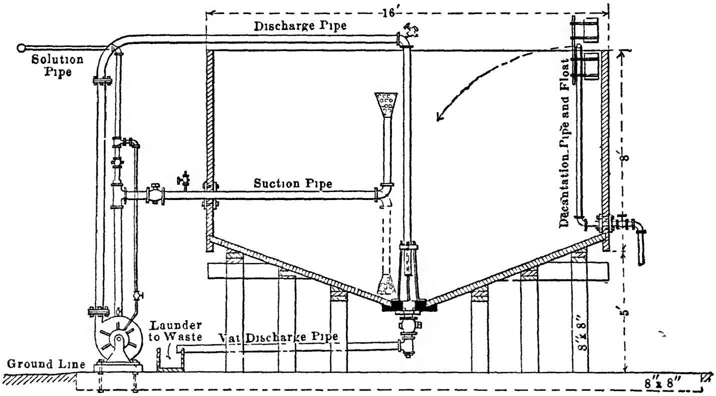


FIG. 7.—DECANTATION-VAT AND PUMP CONNECTIONS.

deposited from the solution can be washed into a discharge-launder and run to waste. In practice, however, it is found that these boxes are not sufficiently large to carry all the solution, and therefore, that portion coming from two of the decantation-vats is run directly to the solution-tanks.

The solution-tanks at the head of the zinc-boxes are two in number, one being used for the weak and the other for the strong solution. They are made of 2-in. redwood throughout and are each 11 ft. 8 in. in diameter and 7 ft. 7 in. deep (inside measurements) having a capacity of 25 tons. Each solution-tank is provided with a 2-in. floating hose, by means of which the clearest solution in the tanks is always supplied to the zinc-boxes. A 3-in. opening in the bottom of each of these

solution-tanks, provided with a valve, permits of the periodic discharge of the accumulated settled slimes into a waste-launder.

Fig. 8 shows the timber foundations supporting the decantation-vats, the conical bottoms resting on three beveled rings as shown. The supports for the agitation-vats are built in the same manner, the supporting rings, however, being placed to line at 45° instead of at 20°. Fig. 9 shows the decantation-vats in course of erection.

There are four sets of zinc-boxes, each set being composed of six round individual boxes or compartments, each compartment being 28 in. in diameter and 2 ft. deep, and having an available zinc-capacity of approximately 5 cu. feet. One of the boxes is used solely for strong solution and two for weak solution, the fourth being so connected that either weak or strong solution may be run through it. The solution leaving the zinc-boxes passes to three sump-tanks, made of 2-in. redwood throughout, each 11 ft. 8 in. in diameter and 9 ft. 7 in. deep (inside measurements) and of a capacity of 32 tons of solution. Two of these tanks are connected together and serve as a weak-solution sump, the other being used for the strong solution.

Fig. 10 gives a good view of the plant shortly before its completion and shows its general arrangement. Fig. 11 gives a nearer view of three of the agitation-vats and shows the tops of two of the decantation-vats. The 4-in. centrifugal pump feeding to the No. 1 agitation-vat is seen partly connected to it. Protruding from the top of the decantation-vat, a little below the center of the picture, is seen the end of one of the 2-in. decantation-pipes.

Method of Treatment.

The accumulated slimes, after having been allowed to dry in the slime-pits as much as practicable, are conveyed to the agitation-vats in ordinary half-ton ore-cars by means of the small, friction-geared hoist already mentioned. Each agitation-vat is provided with an iron grizzly, measuring 3 ft. 3 in. by 9 ft., and having 1.25-in. openings, which is suspended over the vat, to one side of the center. The content of the car is dumped onto this grizzly and the portion that does not pass through of its own weight is trampled, or otherwise forced through, by one or two boys. For some time the material being treated averaged from 20 to 25 per cent. of moisture, and in this condition

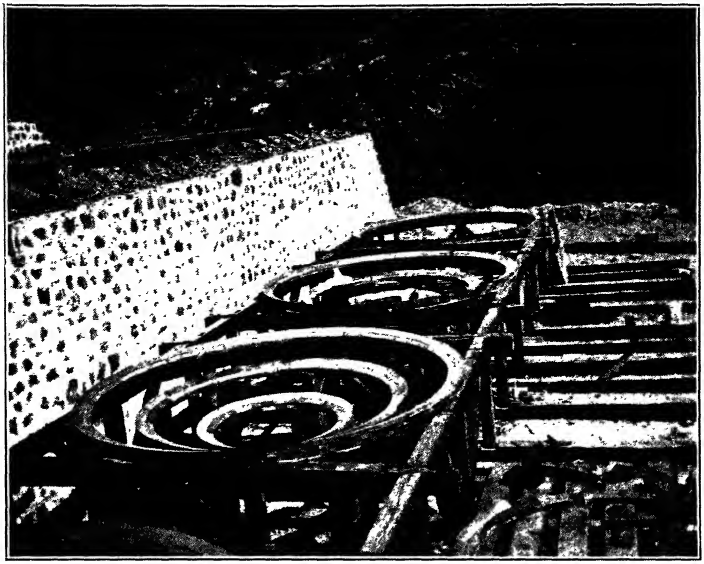


FIG. 8.—TIMBER FOUNDATIONS SUPPORTING DECANTATION-VATS OF SLIME-PLANT

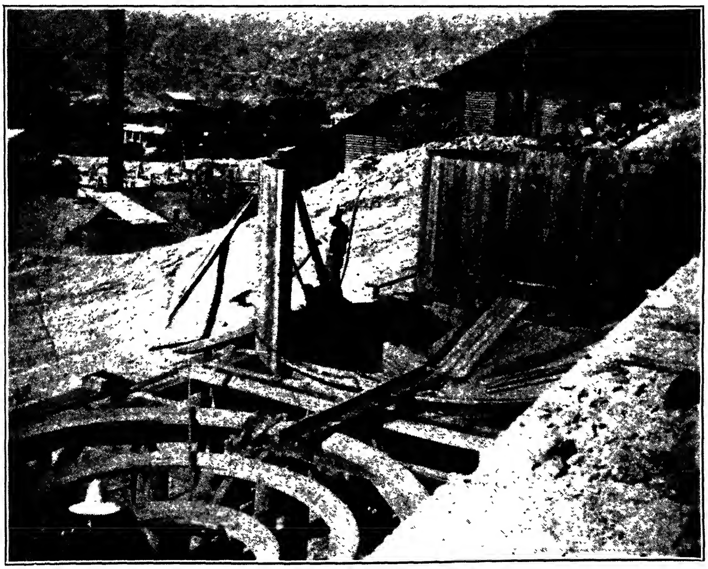


FIG. 9.—DECANTATION-VATS OF THE SLIME-PLANT IN COURSE OF ERECTION.

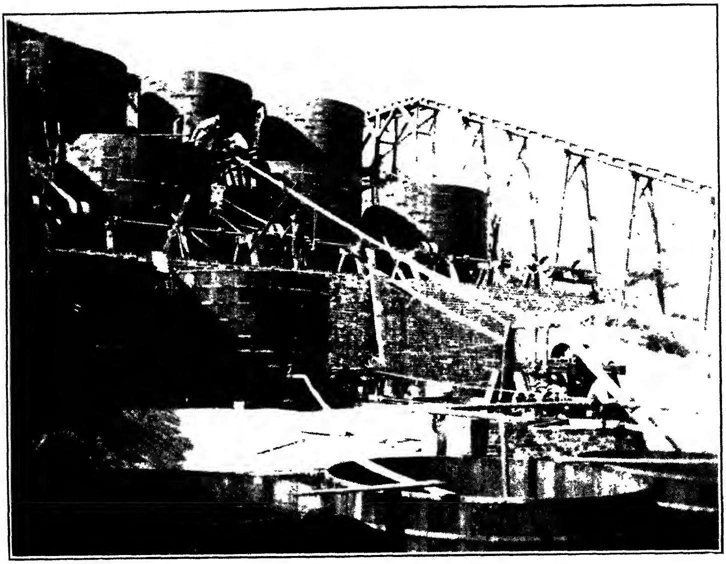


FIG. 10.—GENERAL ARRANGEMENT OF SLIME-PLANT BEFORE COMPLETION.

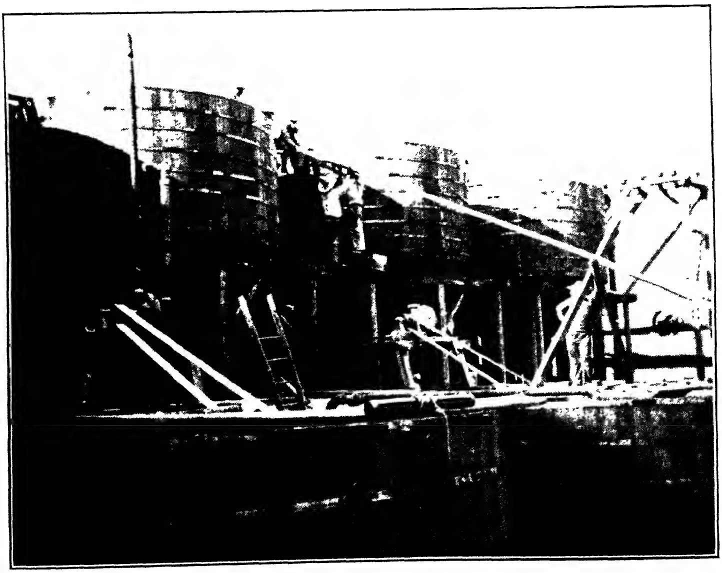


FIG. 11.—THREE OF THE AGITATION-VATS AND TOPS OF TWO OF THE DECANTATION-VATS OF THE SLIME-PLANT.

it was rather lumpy and extremely cohesive. During this time the agitation was very unsatisfactory and the percentage of extraction was consequently lower. A great deal of difficulty was experienced in discharging the vats, since the un-agitated portion of the charge would remain in the pointed bottom of the vat as a tough, putty-like mass, after all the liquid portion had been discharged, and could only be washed out by means of a stream of solution or water under pressure. In such cases, the most effective procedure was to attach a 2-in. hose to one of the valves on the solution-line and sluice the material out, under pressure furnished by the pump, into the launder leading to the corresponding decantation-vat. Our experience, so far, seems to have demonstrated that, in order to obtain the most satisfactory results under the present practice, the best condition of the material is such that the major portion, when dumped on the grizzly, will run through by gravity. In this state the slimes will usually carry from 30 to 35 per cent. of moisture. It is desirable that the percentage of moisture, contained in the slimes when charged, shall be as low as possible, compatible with satisfactory agitation; since it is obvious that the greater the percentage of moisture contained in the slimes, the greater will be the mechanical consumption of cyanide resulting from the loss of cyanide present in the solution contained in the pulp as finally discharged when the treatment is finished. It is true that a certain quantity of water must be added to counterbalance the loss of solution due to the fact that the discharged pulp carries a higher percentage of moisture than the slimes charged; it is equally true, however, that any addition of water, that may thus be rendered necessary, is most advantageously added to the charge in the form of a final wash of water. It seems that the complete drying of the slimes by some cheap, appropriate process, followed by the powdering of the dried slimes before charging them into the agitation-vats, should be productive of improved commercial results. The net, dry tonnage of slimes, constituting a charge, varies; but thus far a charge equivalent to about 15 tons of dry slimes gives more satisfactory results than does a heavier one.

Before commencing to charge the slimes, about 35 tons of solution from the strong-solution sump, usually of a strength

between 0.12 and 0.15 per cent. of KCN, is pumped into the vat and the attached centrifugal pump started. From 75 to 100 lb. of slaked lime is then added and the charging of the slimes commenced. After the required quantity of slimes has been added, a sample of the material passing through the pump is taken, filtered and the clear solution titrated. The necessary quantity of cyanide to bring the solution up to the proper strength is then added. Experiments have been made with various strengths of solution in the agitation-vats, the results thus far showing the use of 0.2-per cent. solution to give more satisfactory results than the use of a weaker solution. The cyanide is placed in perforated buckets or cans and suspended in the charge. It is found, however, that unless the receptacles containing the cyanide be frequently stirred about in the charge, the cyanide dissolves exceedingly slowly. It has been found on different occasions, when this point has been overlooked for any reason, that cyanide broken into pieces about the size of 6-in. cubes and suspended in the charge at about 6 p.m. had not entirely dissolved by 6 a.m. of the next morning. The smaller the proportion of solution to solid matter present, the more noticeable is this tendency of the cyanide to dissolve very slowly. It is also noticed in this connection, that the thicker the charge, the slower is the action of the cyanide on the silver and gold contained in the slimes. During the agitation it is found best to keep the screen at the end of the suction-pipe just as near the surface of the charge as possible, without allowing the entrance of air. By so doing, the material passing through the pump always contains a minimum quantity of solids, and the wear on the pump is consequently lessened. In addition to this, the movement or circulation within the charge is then greatest, since the suction- and discharge-points are then the furthest separated. It is quite probable that a considerable portion of the heaviest and coarsest part of the material treated does not pass through the pump at all, as owing to its greater weight it may never be raised to the height of the suction-screen. The agitation of the mass seems to depend chiefly on the fact that the discharge issuing from the drop-pipe tends to keep the point of the conical bottom free from any settled deposit of slimes; and the thickened material, constituting the lower portion of the charge, keeps

constantly sliding down the inclined sides towards the bottom point. The product issuing from the discharge-pipe, being drawn from the surface of the charge, must pass upwards through the entire mass above, before it can again pass through the pump.

The percentage of solid matter contained in the material passing through the agitation-pumps is determined from samples taken through the bibb-nosed pet-cock tapping the discharge-pipe a few inches above the pump-shell. The results usually show this percentage to be a little less than the percentage of solids contained in the charge as a whole. The average of a number of these samples show that the pulp ordinarily passing through the pumps will carry about 25 per cent., by weight, of solids.

A thorough oxygenation of the mass is found to be an important feature, which becomes more necessary as the proportion of the solid matter to the solution increases. At the commencement of operations, the small air-cock, *e* (Fig. 6), was used to permit the continuous admittance of air to the suction-pipe of the pump. This practice, however, was soon abandoned, because the agitation was seriously affected by it. The entrance of air into the suction-pipe had a detrimental influence on the capacity of the pump, and though the reduction in capacity was apparently not very marked,—due to the fact that, owing to the manner in which the pumps are connected with the vats, the suction side of the pump is, of course, continually under pressure from the pulp in the vat and no suction on the part of the pump is necessary,—nevertheless the effect was found to be injurious to the best agitation. Perhaps the chief trouble was due to the rapid rise to the surface of the imprisoned air immediately on being expelled from the discharge-pipe, following closely the sides of the central drop-pipe. The air-bubbles, breaking on reaching the surface of the charge, caused a splendid surface-movement that was easily mistaken for the thorough agitation of the entire mass. The current of pulp expelled from the discharge-pipe appeared to follow the line of least resistance established by the rising bubbles of air, also rising towards the surface along the central drop-pipe, without effecting a proper scouring of the bottom point of the vat. The present practice is to allow the entrance of a smaller quan-

tity of air into the mass, through the small air-cock, *l* (Fig. 6), and the effect on the agitation is very much less detrimental. In addition to this, a certain small quantity of air will be drawn into the pump almost continuously through the stuffing-boxes, which are seldom kept absolutely tight. The quantity of air added in this way is so small that it affects the agitation but little, if any.

For experimental purposes, one agitation-vat was so connected that the suction of the pump drew directly from the bottom of the vat, while the discharge-pipe entered through the side of the vat at a point about 6 ft. from the top and terminated in a movable curved-pipe which imparted a circular motion to the discharging pulp. Owing, doubtless to the physical condition of the slimes charged, this method of pump-connection was a failure, since the tendency to clog the suction at the bottom of the vat was very marked, and the charges so agitated never completely discharged from the vat of their own accord, but always left more or less of unagitated material remaining, which had to be subsequently sluiced out.

Ordinarily a charge is agitated in the vats from 40 to 44 hr., after which it is discharged into the corresponding decantation-vat, where it is usually given a two days' treatment. Should the charge from the agitation-vat not fill the decantation-vat, enough precipitated solution is pumped up from the strong-solution sump to fill it, and after agitation for half an hour, the charge is allowed to settle. Should the addition of this extra solution be unnecessary, the charge is not agitated, but allowed to settle as long as practicable, the clear supernatant solution being meanwhile decanted off. After the first settling and decantation, the vat is pumped full of weak, precipitated solution, which is usually of a strength approximating 0.1 per cent. of KCN per ton, and the charge is agitated for from 1.5 to 2 hr. by means of the 3-in. centrifugal pump connected with the vat, about 25 lb. of slaked lime being added during the agitation. The pump is then stopped and an additional quantity of slaked lime, usually about 10 lb., is sprinkled evenly over the top of the charge. After settling a few hours, the decantation-pipe is lowered and the settling and decanting of clear solution continued as long as practicable. As many washes and decantations as possible, within the time limit of the treatment, are

given in this manner. When permissible, the last wash given is of clear water, though in order to avoid too great an accumulation of stock-solution a few of the charges have to be washed entirely with weak solution.

When treating charges containing the equivalent of 15 tons of dry slimes, usually four settlings and four decantations can be effected within the 48 hr. of treatment, each decantation averaging about 22 tons of solution; hence about 90 tons of solution are decanted in treating a 15-ton charge, and each decantation removes approximately 58 per cent. of the total solution present. Assuming the wash-agitations to be perfect, the four decantations should then theoretically contain about 97 per cent. of the total values dissolved at the time the washing was commenced.

The settled pulp is discharged through the bottom-valve and the 4-in. discharge-pipe into the residue-launder and is run to waste.

Table VIII. shows the rate of settling per hour, determined at various times, on several different charges.

The pulp, ready for discharging, carries about 50 per cent. of moisture, the contained solution averaging 0.07 per cent. of KCN, and having an average value of approximately $0.40 of gold and 1.50 oz. of silver per ton. These values are of course higher than would be expected to remain in the solution after the several decantations and dilutions had been effected; but as has already been recorded by several different parties operating similar slime-plants, the dissolution of values from the slimes does not cease at the completion of the agitation proper, but continues throughout the washing, and the value of the wash-solution is thus being constantly augmented. This feature, however, is more noticeable with the silver- than with the gold-values, since the gold dissolves much more rapidly than does the silver, and the maximum extraction of the gold-values is obtained earlier. The solution used for washing will always carry a certain quantity of values, which of course results in a corresponding direct increase of the values that would otherwise be carried by the solution contained in the discharged residues. Moreover, it may often be the case that the wash-agitations are not perfect. For these reasons, the solution contained in the discharged pulp will always carry more

TABLE VIII.—*Settling Rate of Slimes per Hour, with Addition of Lime.*

At End of		Settlement (in Inches) of Slimes						
		Test No 1	Test No 2	Test No. 3	Test No 4	Test No 5. (c)	Test No. 6 (c)	Test No 7.
	Proportion of Solution to Slimes	2.5 : 1	2.5 : 1	2 5 : 1	2 5 : 1	2 5 : 1	2 5 : 1	3 3 : 1
	Lime Added per Ton of Slimes. (a)	2 lb.	3 lb.	3 lb.	3 lb.	3 lb.	None (b)	4 lb.
1 hour		11.0	10.5	10.0	16.0	14.0	15.0	22 0
2 hours		21 0	19.0	16 5	26 5	21.0	24 5	36.5
3 hours		27.5	26.0	23 5	33.0	30.0	33.5	51.5
4 hours		33.0	32.0	30 0	40 0	39.0	40 0	54.0
5 hours		36.0	35.5	36.0	42 0	43 0	42.0	57 0
6 hours		38.0	38.5	40.0	43.0	47 0	43.0	58 0
7 hours		39.5	40 0	41.5	44.0	48.5	44.0	59 0
8 hours		40.5	41.0	42 5	44.5	48 5	44 5	59.5
9 hours		41.0	41.5	43.0	45.0	49 0	44 5	59 5
10 hours		41.0	42.5	43.5	45.0	49 0	45 0	59 5
11 hours		41.5	42.5	43 5	....	....	45 0	....
12 hours		41.5	43.0	....	...	...	...	.....

(a) This quantity of lime added was in addition to the lime already contained in the solution ; sufficient lime usually being present in solution that the addition of 5 c c. of strong lime-water to a titration (with silver nitrate), for strength of solution, would make no difference in the titration

(b) See note (a).

(c) Tests No 5 and No. 6 were on material from near the head of slime-pits, and which therefore contained a larger percentage than usual of fine sands.

(Each 2 in of solution equals one ton.)

values than it should, according to calculations based solely upon the successive dilutions and assuming the agitations to have been perfect.

A portion of the sample of the pulp ready for discharging, together with its proper proportion of contained solution, is dried, the assay-results being taken to represent the value of the discharged slimes. Another portion of the pulp is washed and then assayed. On an average, the washed sample will run about $0.40 of gold and from 1 to 2 oz. of silver per ton lower than the unwashed sample.

As previously noted, the 3-in. centrifugal pumps connected with the decantation-vats are the ordinary pumps commonly used for pumping solutions; the only alteration being that the bearing nearest the pump-shell is tapped with a 0.25-in. pipe,

which supplies the bearing with solution under pressure. These pumps run about 4 hr. in each 24, and they have given excellent satisfaction during the 5 months that the plant has been in operation, the only repair-work that has been required on them being an occasional repacking of some of the stuffing-boxes.

For experimental purposes, one of the decantation-vats has been connected with the pumps in such a manner that, by means of loosely threaded elbows, the ends of both the suction- and discharge-pipes are movable, and the suction may be dropped to the point of the conical bottom or may be raised at any height up to about 4 ft. above it; while the discharge-pipe can be raised to the top of the charge or lowered to the bottom. The end of the discharge-pipe is curved, conforming to the circumference of the vat, thus imparting a circular motion to the charge during agitation. While practically this same idea was tried on the agitation-vats, with very poor results, the scheme works very well on the decantation-vats, doubtless due to the fact that the slimes before entering these vats have been thoroughly broken up and mixed in the agitation-vats. Although the agitation in this specially-connected vat seems to be excellent, and to all appearances is better than that taking place in the other decantation-vats, no appreciable difference has so far been noticed in the average assays of the discharged residues.

Table IX., giving a somewhat detailed record of the treatment of one charge, may be taken to represent the usual practice, though the charges then being treated were heavier than those treated at the present time. The usual charge is now but 15 tons of slimes (dry weight), while the proportion, by weight, of solution to slimes present has been increased to 2.5 : 1.

Precipitation.

All solution leaving the decantation-vats is passed through the zinc-boxes before being re-used. The zinc-boxes have to be watched very closely, since, owing to the excess of lime usually present in the solution, difficulty is experienced in obtaining good precipitation. Records are kept of the quantity of solution passing daily through the boxes, together with the assay-values of the solution before and after precipitation. These records show that, during the last 3 months, an aver-

TABLE IX.—*Detailed Record of Slimes Treatment.*

Charge No. 29. Vat No. 1. Net weight of slimes charged, 18 tons. Moisture in slimes as charged, 31.5 per cent Proportion of solution to slimes present, 2 : 1. 100 lb. lime added at commencement of charging.

Assay-value of slimes per ton as charged was $4.34 of gold and 19.22 oz of silver.

TREATMENT IN AGITATION-VAT.

Date and Time	Agitation.	Assay of Solution.		Value Extracted by Solution.		Assay of Tailings		Extracted as per Solution-Assays		Extracted as per Tailings-Assay		Strength of Solution in KCN Sample taken at		Remarks
		Gold	Silver	Gold.	Silver	Gold	Silver	Gold	Silver.	Gold	Silver	Vat. (a)	Pump (a)	
	Hours		Ounces		Ounces		Ounces	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	
Sept 29														
4 p m	......	$0.95	0.85	...	......	..	......	.....	.. ..	....	.....	0.11	...	Commenced charging, 7 a.m. Finished, 4 p m Added 90 lb. of cyanide (NaCN = 125 per cent. of KCN), at 4 p m.
4 p.m..	......	0.90	0.96	.. ..	.. ..	..		..	......	....	...	...	0.09	
6 p.m..	2	1.05	1.01	$2.10	2.02	.	.	48.4	10.5	..	....	0.40	.....	
6 p m..	2	1.15	1.45	2.30	2.90	$2.06	16.10	53.0	15.1	52.5	16.2		0.16	
10 p m .	6	1.20	2.13	2.40	4.26	....	.. . .	55.3	22.2	....	.. ...	0.30	. .	
10 p m .	6	1.30	2.42	2.60	4.84	1.44	14.66	59.9	25.2	66.8	23.7	.	0.22	
Sept. 30.														
2 a.m .	10	1.50	3.35	3.00	6.70	1.24	13.20	69.1	34.8	71.4	31.3	0.23	.. ...	
2 a m .	10	1.55	3.73	3.10	7.46	1.14	11.78	71.4	38.8	73.7	38.7		0.23	
8 a m..	16	1.60	3.99	3.20	7.98	1.03	10.98	73.7	41.4	76.3	42.9	0.19		Added 30 lb. of lime.
8 a m .	16	....	4.28	....	8.56	1.03	10.68	. ...	44.5	76.3	44.4	.	0.19	
2 p m .	22	1.65	4.65	3.30	9.30	. .. ...	. ....	76.0	48.4	.	. . .	0.22	..	
2 p m .	22	1.60	4.75	3.20	9.50	0.92	10.14	73.7	49.4	78.8	47.2	.. ... .	0.22	
8 p.m.	28	1.70	4.76	3.40	9.52	0.82	10.34	78.3	49.5	81.1	46.2	0.19	.. ..	
8 p m.	28	1.65	4.67	3.30	9.34	0.82	10.22	76.0	48.6	81.1	46.8	. .. .	0.18	
12 p m.	32	1.70	4.83	3.40	9.66	0.82	10.26	78.3	50.3	81.1	46.6	0.18	.. ... .	
12 p m..	32	1.80	4.80	3.60	9.60	0.92	10.04	82.9	49.9	78.8	47.7	. ...	0.18	
Oct. 1.														
4 a m.	36	1.70	4.94	3.40	9.83	0.82	9.85	78.3	51.4	81.1	48.7	0.17	. ....	Commenced to discharge into decantation-vat. Discharging in 1 hour.
4 a m..	36	1.75	4.81	3.50	9.62	0.82	9.70	80.7	50.1	81.1	49.5	. ...	0.17	

(a) Vat-sample taken from surface of charge, in vat Pump-sample taken from discharge-pipe, near pump.

TABLE IX.—(*Continued*).

TREATMENT IN DECANTATION-VAT.

Date	Time	Solution Decanted						Remarks
		Quantity	KCN	Assay-Value		Total Assay-Value		
				Gold	Silver	Gold	Silver	
		Tons	Per Cent		Ounces		Ounces.	
Oct. 1...	5 a m.	... ...	....	... ...	... .	..	....	Finished receiving charge from agitation-vat. 20 lb. lime added while being charged. Let settle for 3 hours
Oct. 1 . Oct. 1 ...	8 a m. 3 p m	18 0	0.18	$1 70(b)	4 84(b)	$30.60	87.12	Commenced decanting Finished decanting. Added 18 tons 0 10 per cent. KCN solution, and 40 lb. lime. Agitated for 2 hours. Let settle for 6 hours.
Oct. 1 .. Oct. 2 . .	11 p m 4 a.m.	18 5	0.14	0.91	2.56	16.83	47 36	Commenced decanting Finished decanting. Added 18 5 tons of 0 11 per cent KCN solution, and 40 lb. lime. Agitated for 2 hours. Let settle for 4 hours.
Oct. 2 . Oct. 2 ..	10 a m. 3 30 p m.	19.0	0.11	0 48	1 44	9.12	27 36	Commenced decanting. Finished decanting. Added 19 tons of 0.09 per cent. KCN solution, and 40 lb. lime Agitated for 2 hours. Let settle for 5.5 hours.
Oct. 2 Oct. 3	11 p m 3 a m	18 0	0 09	0 30	0.88	5.40	15 84	Commenced decanting. Finished decanting. Discharged vat.
Total	....	73 5	. ....	.. ..	.....	$61 95	177 68	

(*b*) In all these decanted-solution samples, the value of the solution, as added to charge, has been deducted.

NOTE.—Assay of discharged residues (unwashed): $1 03 of gold, 9.52 oz. of silver Extaction, 76 27 per cent of gold and 50 47 per cent. of silver. Assay of discharged residues (washed). $0.62 of gold, 8.38 oz of silver.

Moisture contained in discharged residues, 51.4 per cent. Assay-value of solution was $0.40 of gold and 1 24 oz. of silver. Strength, 0.09 per cent. of KCN.

Extraction indicated by values contained in decanted solutions: 79.30 per cent. of gold and 51 36 per cent. of silver.

Total time of treatment: In agitation-vats, 45 hr.; in decantation-vat, 48 hours.

age of practically 48 tons of strong and 117 tons of weak solution, or a total of 165 tons, were passed through the boxes daily, the average assays of the solution being approximately as follows:—

	Strong Solution.		Weak Solution	
	Gold	Silver	Gold	Silver.
		Ounces		Ounces.
Entering zinc-boxes.	$1.05	2.90	$0.60	1 70
Leaving zinc-boxes.	0.10	0.40	0 10	0.35

The zinc-boxes, having a combined total shavings-capacity of approximately 120 cu. ft., the rate of flow of the solution through the boxes during 1904 averaged 1.37 tons per cu. ft. of shavings per 24 hours.

The precipitates recovered are always of lower grade than those obtained in the sand-plant, because, in spite of all precautions, a certain quantity of suspended slimes will be carried with the solution into the zinc-boxes and will be there retained, thus lowering the grade of the precipitates. The highest-grade precipitates yet recovered from the slime-plant assayed approximately $6,800 of gold and 17,300 oz. of silver per ton.

Tonnage, Percentages, etc.

The normal capacity of the plant, while treating 15-ton charges and allowing a two days' treatment in both agitation- and decantation-vats, is 30 tons per day. During the last quarter of 1904, approximately 2,550 tons of slimes (net dry weight) were treated, and the extraction during this period, shown by the differences between assays of the charge and the residue, was 74.9 per cent. of the gold and 49.2 per cent. of the silver. During this period, the assay-values of the slimes, as charged, averaged approximately $4.35 of gold and 19.25 oz. of silver per ton.

The consumption of cyanide, zinc and lime per ton of dried slimes treated during this time was:—Sodium cyanide, 4.42 lb.; zinc, 0.957 lb.; and lime, 13.95 lb. The sodium cyanide consumption is equivalent to 5.52 lb. of potassium cyanide.

Since the above was written, the consumption of cyanide has been steadily decreased, and during the last two months

(March and April, 1905), it has averaged 3.56 lb. of sodium cyanide (equivalent to 4.40 lb. of potassium cyanide) per ton of slimes treated.

The average extraction of silver for the last three months has been 51 per cent.

Table X. gives the operating costs per ton of slimes treated.

TABLE X.—*Working-Costs per Ton of Slimes Treated.*

Cyanide (4.42 lb @ $0.63),	$2.785
Zinc (0 957 lb. @ $0.30),	0.287
Lime (13 95 lb. @ $0 0118),	0.165
Other supplies,	0.238
Lubricating,	0.033
Labor,	0.491
Salaries,	0.748
Assay-office (labor and supplies),	0.066
Power (ditch, maintenance and supplies),	0.621
Miscellaneous (lighting, etc),	0.002
Management and general expenses,	0.179
	$5.615

As elsewhere throughout this paper (except when otherwise stated), sums of money are here given in Mexican currency, $2 (Mex.) being assumed as equivalent to $1 (U. S.). This relation, however, varies somewhat with the rate of exchange. Thus, at the time represented by Table X., $5.615 (Mex.), the total given in that table, was equivalent to only $2.66 (U. S.). The cost of realization on the precipitates produced is not included in the above working-costs. For the reasons already given in the portion of this paper relating to the sand-treatment, these expenses are unusually high. The average cost of realization on the precipitates produced in the slime-plant, per ton of dry slimes treated, is:—Government taxes, $0.856; treatment-charges (including transportation-expenses), $1.202; total, $2.058.

I wish to acknowledge my indebtedness to Mr. Wm. T. MacDonald, Mill Superintendent of the Palmarejo and Mexican Gold Fields, Ltd., for his valuable assistance in the preparation of this paper.

Biographical Notice of Thomas M. Drown, M.D., LL.D.

BY R W. RAYMOND, NEW YORK CITY.

(Washington Meeting, May, 1905 *)

THE sudden death of Dr. Drown, on Nov. 17, 1904, brought to multitudes the pang of personal loss. Of all those who, as students at Lafayette College, the Massachusetts Institute of Technology and Lehigh University, were brought under his influence, not one can have forgotten him, and all will now acknowledge, with an unfading gratitude, what they owe in professional equipment to his wise, clear, skillful guidance, and in character to his sympathetic, stimulating personality. Outside of this wide circle, the experts of both hemispheres will lament the departure of one who, in his department of scientific investigation, both knew what work was needed, and how to do it so that it needed not to be done again. The older members of the American Institute of Mining Engineers will remember with gratitude the part he took, as Secretary from 1873 to 1884, in promoting the interest of that organization, and in shaping the plan and policy which it has followed with such noteworthy success. And, in addition to all these (though partly included among them), there are a host of friends, who can scarcely think of the public loss by reason of their own.

Thomas Messenger Drown was born March 19, 1842, at Philadelphia, Pa. His parents were natives of New England; and he was the youngest of their three sons. He received his preliminary education in the public schools and the High School of Philadelphia, from which he was graduated in 1859. Be-

* Shortly after the death of Dr. Drown, I contributed to the New York *Engineering and Mining Journal* of Nov. 24, 1904, a preliminary notice of his career, a part of which is included in the present more extended sketch, prepared at the request of the Council of the Institute. For much additional material herein contained, I am indebted to many personal friends of Dr. Drown, and especially to Prof. H. P. Talbot, of the Massachusetts Institute of Technology, author of an admirable article in the *Technology Quarterly*, who kindly consented to the exchange of advance copies of our manuscripts.—R. W. R.

fore this, he had evinced an ardent love for chemistry by starting, in his father's house, a laboratory, which was soon removed by parental authority to a small, separate building, erected for the purpose by parental sympathy. But he loved to be near his laboratory; and many years later, when he had a house of his own, he devoted one floor to this purpose. It was not surprising, therefore, that from the High School he went to the University of Pennsylvania, primarily for the purpose of studying chemistry. But this science was at that time scarcely a profession by itself; and he took, in connection with it, the medical course, receiving in 1862 his degree as Doctor of Medicine, with such high commendation of his proficiency in therapeutics and surgery as enabled him to secure at once the much-coveted position of physician and surgeon upon a trans-Atlantic sailing-packet. In this capacity he made one round trip, and then definitely returned to his first love, chemistry, to the study of which, first at the Sheffield school under Brush and Johnson, and afterwards at the Lawrence Scientific School under Wolcott Gibbs, he devoted about three years. Dr. Gibbs remembers him as "a dextrous worker," and "a gentleman by nature," and still possesses the notes of work done by him in 1864 upon a new method of separating cerium from lanthanum and didymium.

In 1865 he went to Europe to spend about three years and a half, principally at Freiberg, Saxony, and at Heidelberg, Baden. At the Freiberg Mining Academy, he acquired a valuable training in metallurgical chemistry; and at Heidelberg University he had the privilege of becoming a pupil and friend of the great teacher and investigator, Bunsen. Here also he first met Miss Helen Leighton, whom he married in 1869, at her home in England, and who, after thirty-five years of loving companionship, survives to mourn his death.

In 1869, at the age of 27, Drown returned to America with an equipment of thorough theoretical and technical preparation which would be considered, even now, unusual, and was at that time, for so young a man, almost unique. For a short time he was instructor in metallurgy at the Lawrence Scientific School; but in 1870 he returned to his native city of Philadelphia, where he established his office and laboratory as analytical and consulting chemist. In 1874, becoming the Professor

of Chemistry at Lafayette College, Easton, Pa., he took up his residence in that city.

Meanwhile, in May, 1871, he had been present at the meeting in Wilkes-Barre, Pa., which organized the American Institute of Mining Engineers, and had been elected a Manager in its first Council. This position he resigned in 1873, to accept the office of Secretary, which he held for more than ten years. In 1881, he resigned the professorship at Lafayette, and in 1883 the secretaryship of the Institute. During a period of several years, including these dates, he was obliged to sacrifice his professional plans and labors to the demands of the business formerly built up by his father, and left, by the illness of his brother, without efficient management. This is not the proper place, nor have I the necessary knowledge, for a full account of that episode; but I cannot forbear to testify, from what I do know, that, in my judgment, it constituted the crowning proof furnished by Dr. Drown's career, not only of his high sense of honor, but also of his extraordinary executive ability. Turning, at a moment's notice, from the familiar and congenial work of his life to a business with which he had had no previous acquaintance,[1] he mastered its details; estimated its needs and prospects in view of modern conditions and competition; and finally, with astonishing skill, though at the cost of a heavy (and neither legally nor morally obligatory) personal sacrifice, conducted its liquidation, so as to leave no stain of bankruptcy upon his father's name. Other men, chivalrously ready to make a similar sacrifice, might have made it in vain; other men, capable of comprehending the business situation, might have refused the quixotic sacrifice; few indeed, I think, could have accomplished what Drown did—and fewer still could have remained silent concerning it thereafter. I have hesitated to break, even to this extent, his modest and magnanimous silence. But I cannot withhold my witness concerning a matter which established forever my supreme admiration and love for him.

In 1885 he found himself able to accept the professorship of chemistry in the Massachusetts Institute of Technology—a position which he occupied until he became, in 1895, the President of Lehigh University.

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[1] The manufacture of umbrellas, in which, for a generation, the house of Wm. A. Drown & Co. had held acknowledged pre-eminence.

Here I pause to review his work at Lafayette College and as Secretary of the Institute, since this covers the period of my own most intimate association with him—although our friendship continued through the subsequent years of his life. During a large part of the period of his professorship at Lafayette College, I was, as a non-resident professor, his colleague in the faculty of that institution. Whenever I visited Easton, in connection with my lectures, I was welcomed as a guest in the hospitable and refined household of Dr. Drown; and in many a conversation with him I learned much of his work and methods. Having been a student of chemistry at more than one institution in Germany, I was interested and surprised by certain views and customs of his, very different from those to which I had been accustomed abroad.

In the first place, my experience had been that a professor of chemistry delivered a course of lectures on the subject, of which the students took notes, and that the laboratory-work of all except the most advanced students was supervised by an assistant. I found that Drown, on the contrary, made his assistant give the lectures, and devoted himself specially to the individual students—even the beginners—in the laboratory. As he expressed his feeling to me, he "would rather make chemists than talk chemistry."

In the second place, I had been accustomed to laboratory-work, requiring the students to analyze artificially-prepared samples, in which they had no interest beyond that of "getting the right answer;" this being already known to the assistant in charge, so that its re-statement would add nothing to the sum of human knowledge. But I found that Drown put every individual student, at the earliest possible moment, upon an original investigation, calculated to interest him; that this investigation was made jointly by teacher and pupil; and that the teacher's teaching was mainly given in the form of daily criticism and advice concerning methods, manipulations, and the significance to be attached to their results.

This practice is, I think, more general now than it was at that time, more than 30 years ago. Certainly Drown never claimed it as original with himself,[2] though I have always be-

[2] On the contrary, he declared it to have been the method of his instructor at the Lawrence school.

lieved that he began it at an earlier period of the course of instruction, and devoted to it more personal and detailed attention, than other teachers of his rank. At all events, the result was that "Drown's men" were universally recognized as intelligent, practical and skillful chemists, and were in special demand on that account.

Another peculiarity which I noticed was his constant and dominant desire to perfect rapid and accurate methods of analysis. Foreseeing the important part which chemistry would soon play in industrial enterprises, he sought especially to perfect the equipment and increase the usefulness of industrial chemists. In pursuance of this ambition, he was continually putting his pupils upon problems involving the facility, rapidity and accuracy of laboratory-methods. On this point, Prof. Edward Hart, of Lafayette College, formerly his assistant, writes me:

"He disliked 'rule of thumb' work, and in that way was a great teacher. Everything was questioned; and he was full of ideas as to new ways of doing things. I tried many of these, as did ——— and several others. Some of them failed, but Drown was very persistent, and simply would not give up, so long as he could think of any further variation of the new idea I remember that we tried to separate iron and alumina by volatilizing the former with hydrochloric acid gas, and failed, time after time, to get a satisfactory separation At last, we gave up in despair; but we were on the right track—it has since been done in Gooch's laboratory.

"Dr. Drown invented the Gooch crucible too; but, though we tried many, many times, we did not succeed in making it work, simply because we did not think of using asbestos fiber in filtering The paper we used *would* clog with precipitate, so that filtration ceased.

"As you know, there was hardly a corner in iron-analysis which he did not explore and illuminate. So rapid is progress that some of his work has been lost sight of; but it is there; and it all counted in the present-day development."

This testimony is amply corroborated by the following list of papers contributed by him to the *Transactions* of the Institute:

Title.	Volume	Page
Attainment of Uniformity in Bessemer Steel, ...	i.	85
Incidental Results of Danks's Puddler, ...	ii.	28
Determination of Sulphur in Pig-Iron and Steel, . . .	ii.	224
Condition of Carbon in Gray and White Iron, ...	iii.	41
Pulverized Zinc, and Its Uses in Analytical Chemistry, .	vi.	508
Experiments on the Removal of Carbon, Silicon and Phosphorus from Pig-Iron by Means of Alkaline Carbonates, .	vii.	146
Note on the Determination of Silicon in Pig-Iron and Steel,	vii.	346

Title	Volume	Page.
Determination of Silicon and Titanium in Pig-Iron and Steel,	viii.	508
Determination of Sulphur in Sulphides and in Coal and Coke,	viii.	569
Condition of Sulphur in Coal, and its Relation to Coking,	ix.	656
An Experiment in Coal-Washing,	xiii.	341
Influence of Silicon on the Determination of Phosphorus in Iron,	xviii.	90
Biographical Notice of Theodore D. Rand,	xxxiv.	695

To this list should be added those papers, in the authorship of which Dr. Drown associated his own name with those of his assistants in the work which he had planned and directed. Such recognition of the credit due to a subordinate was not as common once as it is now. I remember, at least, that the great professors abroad used to avail themselves without scruple of the labors of their subordinates, either making no acknowledgment at all, or else, at most, paying the debt with a complimentary phrase, inserted somewhere in the text. But Drown knew what inspiration young men may receive from the association of their names, as joint authors, with names already famous.

The following papers belong under this head:

Joint Author	Title	Volume	Page
N. H. Muhlenberg,	Solution of Pig-Iron and Steel for the Determination of Phosphorus,	x	85
P W. Shimer,	Analysis of Iron-Ores Containing both Phosphoric and Titanic Acids,	x.	137
Alexander G. McKenna,	Direct Determination of Aluminum in Iron and Steel,	xx	242

But the foregoing list by no means comprises all of Dr. Drown's contributions to the *Transactions*. These volumes contain also his remarks in discussion of the following topics, presented primarily in the papers of other members:

Graphitic Carbon (i., 238); Tests of Steel (ii , 122); Proportion of Oxygen in Coals (ii , 158); Annealing Spiegeleisen (iii., 424); Analyses of Westchester Aluminous Ores (ix , 19); Regelation of Crystalline Salts (ix., 303); Methods for Determining Manganese (x., 107); Methods for Determining Sulphur (x., 189, 194), Methods for Determining Silicon (x., 194, 200, 325); Separation of Silica in Phosphorus-Determinations (x., 327); Analysis of Carbonite or Natural Coke of Virginia (xi., 448); Method of Coal Analysis (xi., 449); Use of Calcium-Chloride Solution in Separating Coal from Slate (xvii., 145), Terms for Describing the Color and Odor of Surface-Waters (xvii , 340); Reduction of Ferric

Sulphate in Volumetric Analysis (xvii , 412); Analysis of Wassaic Pig-Iron (xvii., 473); Action of Alkaline Carbonates on Pig-Iron (xvii , 543); Method for Phosphorus Determination (xviii., 711); Magnetic Concentration of Iron-Ore (xx., 582); Physics of Steel (xxiii., 610); Phosphorus Determinations in Steel (xxv., 1012)

Almost without exception, the papers thus discussed by Dr. Drown had been prepared under the stimulus given by his leadership to the investigation of chemical methods; and our volumes contain innumerable papers and discussions (not mentioned above, because he did not personally take part in them), which were likewise due to his initiative and example—"symposiums" on various branches of analysis and assaying, and criticisms of existing processes, as well as recommendations of new ones. It is not too much to say that the movement he thus inaugurated has made this department of investigation a characteristic feature of the *Transactions* of the Institute. Of course it was not new in scientific literature. Professors and analysts had discussed such topics before. But Drown managed to arouse the interest and co-operation of a class previously content, as a general rule, with the performance of daily routine—the chemists of metallurgical works, for instance, who had to make, day after day, numerous monotonous analyses of the same sort of material for the same limited commercial purpose, and who might easily drop into the mood of drudgery, and fancy themselves shut out from the wider usefulness and higher reputation of scientific investigation. In the training of men for just such places, Drown gave them at the outset, as I have already noted, a taste of the joy of independent, original work; and many of them afterwards realized that the duty of performing hundreds of operations of the same kind gives the best possible opportunity for thoroughly testing improvements of methods and manipulations. The resulting benefit to the profession at large has been amply recognized; but the boon conferred upon obscure individual workers, in showing them that drudgery need not make a mere drudge out of a man, is incalculably greater. Without claiming *aboriginality* (if I may coin a word) for his spirit, purpose or means, I do avow that, as a result of his work as a teacher and author, and the spirit of his administration as Secretary of the Institute (cordially imitated by his successor in that office), our *Transactions* have been always hos-

pitably open to records of practice and experiment, and recommendations of improvement, properly stated and supported, however unimportant they might, at first glance, seem to be. If the washer of beakers and bottles, or the grinder of samples for analysis, suggests a new way to wash bottles or grind samples which is claimed to be in any respect better than the old, his contribution is as seriously considered, and, if meritorious, as cordially accepted by our Council, as if it dealt with theories of molecular structure or obscure chemical reactions. I emphasize this proposition, not only in praise of Dr. Drown, who did so much to establish the principle, but also in reply to occasional friendly criticisms and suggestions concerning the relatively trivial subjects of some of the papers in our *Transactions*. As a general rule, nothing is practically unimportant which has to be repeated in hundreds of establishments many times a day; and, above all, the encouraging recognition of those who seek to improve practice in such small particulars is the way to enlist, as eminent contributors to the technical literature of the future, the ambitious beginners of to-day.

This leads me to mention other aspects of the work of Dr. Drown as Secretary of the Institute. He accepted this position (resigning for that purpose his office as Manager) in 1873, and held it until the middle of 1883, when the pressure of other duties obliged him to give it up. During those ten years, the membership had grown from 22 to about 1,300, and the Secretary, besides taking care of the increasing list, the collection of annual dues, the necessary correspondence, the mailing of volumes, etc., had conceived in 1877 and conducted thereafter the plan of preliminary publication in pamphlet-form which has been pursued ever since. The system of financial accounts was likewise devised by him. In fact, he fixed so wisely the procedure in every department of the Institute's work that I, as his successor, have done little more than continue on a larger scale the methods established during his administration, and at his suggestion, by the Council of the Institute.

No wonder the work became at last too heavy for him, even if he had been able to give to it the whole of his time and strength. At the time of his resignation, he had but one assistant; and the publication of the current volume of *Transactions* was delayed, because he had undertaken,—as if the or-

dinary work were not enough!—the preparation and printing of a consolidated Index, covering the ten volumes he had edited.[3]

In June, 1879, Pardee Hall, the home of the scientific department of Lafayette College, then containing the office of the Secretary, and the library and other possessions of the Institute, was destroyed by fire. The conflagration was so sudden and swift that there was not time to save all the valuable contents of the building, and a choice had to be made. Secretary Drown made that choice instantly, generously and wisely. Realizing that the library of the Institute, consisting mainly of files of technical journals and the proceedings of technical societies, received by way of exchange, could probably be replaced if lost, whereas the loss of the records of the Institute itself, and the stock of back-volumes of its *Transactions*, would be practically irreparable, he decided at once to save these, and let everything else go. Of course he was surrounded by students, eager to assist in the work of salvage. But everybody knows how indiscriminate, and even ludicrous, is the aid rendered by excited individuals on such occasions; and the achievement of the Secretary in that tumultuous hour was a wonderful evidence of his quiet, clear-headed, executive ability. For he so directed the labors of his young assistants that they rescued from destruction just what he deemed most valuable. When that had been accomplished—and it was completely accomplished—there was no time for anything more. Not until that moment did others realize, what he had known all the while, that he was deliberately saving to the Institute the invaluable records of its past, at the sacrifice of his own professional library, occupying a room in the same building. This sacrifice was, to some extent, made up to him through the hearty appreciation of his fellow-members, which found substantial expression at a banquet, held in connection with the Montreal meeting of the Institute, in September, 1879, in the presentation to the Secretary of a check for several thousand dollars, contributed by a large number of his grateful colleagues.

[3] This, by the way, is another of the features, introduced by Dr. Drown, at the cost of extra labor on his own part, which have rendered our *Transactions* specially useful to students

At the annual meeting of February, 1884, the Council announced his resignation in the following terms:

"The Council received with regret, at the close of the year 1883, the resignation of the Secretary of the Institute, Dr. T. M. Drown, who was forced by the pressure of private affairs to retire from this position after years of faithful and skillful service. As a testimony of the esteem and gratitude of the Institute, but not less in recognition of the professional eminence of Dr. Drown, and of the great benefit which his labors have conferred upon a most important department of metallurgy, viz., the development of rapid, convenient and accurate methods of chemical analysis; and in recognition also of the important part which Dr. Drown has taken in extending among American works the practical application of chemical tests and methods, the Council recommends that Dr. Drown be elected an Honorary Member of the Institute. The proposal of his name for such election has been signed by 15 members, in accordance with the Rules; but the Council does not doubt that each and every member of the Institute would have been equally willing to sign such a proposal."

Dr. Drown was thereupon unanimously elected an Honorary Member; and the announcement of this result was received with enthusiastic applause. Thirteen years later, the Institute testified its undiminished sense of his merits and services by unanimously electing him its President.

Into his work at the Massachusetts Institute of Technology, he carried the characteristics which he had already shown elsewhere. I cannot do better than adopt, under this head, the language of Prof. Talbot.[4]

"The larger number of students in his classes forced upon him the adoption of class-room instruction to a degree which was always a source of regret to him, yet he maintained his practice of spending a part of nearly every day in going about the laboratories among his students, encouraging, counselling, and stimulating them to intelligent, critical work. In 1888, he was appointed head of the chemical department; and, on the death of Professor Lewis M. Norton, in 1893, he also assumed charge of the course of chemical engineering. In this capacity, he exhibited clear judgment in the extension of the curricula of these courses demanded by changing conditions, and encouraged the co-workers of all grades in the department by helpful advice, urging the expansion of the work of the individual and promptly recognizing success and ability by unsolicited recommendations for promotion. In this administrative office, as in his teaching, it was his quick and generous appreciation of all that was good in the work of his associates, combined with the unfailing kindness of his criticism and the recognized breadth of his learning, which brought willing workers to his side."

In 1887, the Massachusetts Board of Health placed in the hands of Prof. Drown the chemical department of a thorough

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[4] *Technology Review*, vol. vii., No. 2, Boston (1905).

examination of the inland waters of the State and an inquiry concerning the purification of sewage, authorized by the Legislature. In the execution of this duty, many thousand samples of water were analyzed at the laboratory of the Institute of Technology, of which Prof. Ellen H. Richards was in charge as his assistant.[5]

But these figures of themselves mean little. Nothing is easier than to accumulate vast quantities of routine-observations, unchecked as to accuracy, undirected as to specific purpose, unclassified as to meaning, undigested and indigestible. This work was admirable, not because it was voluminous, but because, notwithstanding its volume, it was so well planned, well done, and fruitfully interpreted. As Prof. Talbot says:

> "Few men could have been found with such admirable qualifications as were combined in Dr Drown for this enormous task of testing old and devising new methods of analyses, of systematizing records and, above all, of giving vitality and worth to the mass of data obtained. His familiarity with large problems and his wide knowledge of men and affairs, gained while Secretary of the American Institute of Mining Engineers, enabled him to co-ordinate and interpret the work of chemists, biologists and engineers, while his editorial experience was invaluable in the preparation of reports; and to this must be added his acquaintance with chemistry and medicine, his active mind, so fertile and resourceful, and his sane judgment in scientific affairs To say that no records were allowed to leave the laboratory which were not scrupulously neat, and subjected to repeated verification, or that weeks were spent in studying possible points of weakness in analytical methods before their adoption is, of course, to mention important details; but the far-reaching influence of the pioneer work done by Dr Drown and his assistants in these years cannot yet be estimated. It is recognized as authoritative by the scientific world, and has become both the inspiration and the model for many other investigations of the same sort, which would not have been possible at this time except for the painstaking thoroughness with which the first comprehensive and continued study of a large number of water-supplies was organized and executed."

Meanwhile, the analytical and experimental work connected with sewage-purification was mostly done at Lawrence, Mass., in laboratories which Prof. Drown visited almost weekly for nearly eight years.

To the report of 1890, embodying the results of only two

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[5] The number of these separate analyses had reached about 4,750 in 1890, when the first extended report of this work was issued. On Feb. 15, 1893, the analysis of the 10,000th sample was celebrated by a dinner at the house of Mrs. Richards, as a reunion of all who had participated in the work. In 1897, when this department was transferred to the new laboratories in the State House, more than 18,000 analyses had been made.

years' work, he contributed a discussion of the sanitary chemistry of domestic water-supplies, dealing respectively with (1) The Distinction between Normal and Polluted Waters; (2) The Chemical Evidence of Pollution in Waters; (3) Normal Chlorine; (4) The Idea of Permanence, and of Various Degrees of Susceptibility to Decay in Organic Matter in Water; (5) The Absence of Dissolved Oxygen, and the Putrefactive Changes of Organic Matter in Some Waters at Considerable Depths; (6) The Effect of Growing Plants in Obliterating Evidences of Bacterial Action in the State of Change of Organic Matter; (8) The Essential Differences in Character of Surface- and Ground-Waters Which Influence the Interpretation of Analyses; and (9) The Influence of the Season of the Year on the Composition of Surface-Waters.

Of this work, Mr. H. W. Clark, Chemist for the Mass. State Board of Health, says, in a recent letter:

> "Looking over the articles that have been left in print in the reports of the Board with his [Dr. Drown's] name attached, only one who has known thoroughly how much really belongs to him to which his name is not attached can understand how small a part of all his work for us is represented by them; and yet this list in its way is a remarkable one. In the special report of the Board for 1890, upon 'Examination of Water-Supplies,' there is an article by him upon the 'Interpretation of the Chemical Analysis of Water.' I think that no one conversant with the subject can deny that it was the first thoroughly scientific and yet common-sense exposition of this matter, a classic when published, and certainly of the utmost value even to-day."

Other, and scarcely less important, papers were published in later reports on The Amount of Dissolved Oxygen Contained in Waters of Ponds and Reservoirs at Different Depths (1891); The Effect of the Aeration of Natural Waters (1891); The Interpretation of Water-Analysis (1892); The Amount of Dissolved Oxygen Contained in the Waters of Ponds and Reservoirs at Different Depths in Winter, under the Ice (1892); The Amount and Character of Organic Matter in Soils and its Bearing on the Storage of Water in Reservoirs (1893); and The Composition of the Water of Deep Wells in Boston and Vicinity (1894).

Perhaps the most widely known and influential feature of this great investigation was the preparation of the famous "Map of Normal Chlorine" for the State of Massachusetts, upon which the results of chemical analysis were plotted in

"iso-chlor" lines, like topographical contours, so that the normal amount of chlorine (due to the soil or to moisture from the ocean) contained in the uncontaminated surface-waters of a given locality could be seen at a glance. This amount is affected by the direction and force of prevailing winds, as well as by distance from the coast, etc.; and the "iso-chlors" are consequently irregular curves, the position of which could not be deduced *a priori*, but must be determined by patient and minutely accurate work. The amount of normal chlorine varies from 0.08 to more than 2 parts in 100,000. Without knowing the local figure, the chemist could not infer from the analysis of a sample whether the water was pure or impure. But with the map before him, he could confidently regard any excess of chlorine above the local normal as a measure of the contamination, due to population, etc.

Such a graphic representation of analytical results was, of course, not a new idea. Probably the only original contribution of Prof. Drown to the scheme was the coinage of the terms, "iso-chlors" and "normal chlorine," which have become classic. The real merit of this map was, that under his acute, careful and unremitting supervision, the work had been so carefully done, and the data so thoroughly discussed and accurately plotted as to render the graphic result an unerring guide. In one case of which I happened to hear (and there may have been many such cases), a farmer from the hill-country, whose sample of drinking-water, though low in chlorine, had been condemned upon analysis, protested that some error must have occurred, since the water had been taken from a brook, flowing from a spring, high above human habitations. But a subsequent careful survey, showing that the spring was accessible to the cattle of a mountain pasture, vindicated the verdict of the laboratory.

Similar maps have been prepared for other States after the pattern of this one; but it is safe to say that not one of them has been based upon so great an array of systematic observations, carefully made and intelligently interpreted.

After leaving Boston in 1895, to become President of Lehigh University, Prof. Drown, as the consulting chemist of the Massachusetts Board, visited the State House laboratories six or seven times a year; and in 1898 he accepted a similar advi-

sory relation to the Massachusetts Department of Food- and Drug-Inspection. Mr. Clark and Mr. Leach, chemists in the State House laboratories, testify warmly to his helpfulness as a kindly critic, and to the thoroughness with which, even amid his administrative duties as a college president, he kept himself abreast with progress in sanitary investigations. Mr. Leach emphasizes the latter quality, by virtue of which Prof. Drown rendered most valuable assistance:

> "Besides having a valuable library of his own, including complete files of most of the technical journals bearing on health matters, he was one of the most widely-read men I ever met. If current information on any subject was needed, Dr. Drown was especially helpful in bringing it to light, and was frequently of great service in this way."

In 1895, yielding at last to an urgent appeal, he accepted the Presidency of Lehigh University, at South Bethlehem, Pa. This important step, involving the abandonment of the special work, so congenial to him, in which he had achieved such high distinction, was taken, as I had opportunity to know, with no little hesitation, and largely in response to the persuasive appeal of his old friend, Eckley B. Coxe, a trustee of the University. The death of Mr. Coxe, after Prof. Drown's acceptance, but before his inauguration, was a severe blow, depriving him of a wise and zealous co-worker, and greatly enhancing the difficulties of the new problem before him. But he did not let it move him to draw back from the labors to which he had pledged heart and hand; and the loyal support of the Trustees, Alumni and friends of the University was all the more cordially given, in view of this sorrow and disappointment.

Lehigh University had been brought face to face with a severe struggle for existence by a temporary failure of revenue from the securities in which its endowment was invested. Such disasters have occurred to other institutions—for instance, to Johns Hopkins, and even to Stanford University, now so rich. To the lasting honor of the Trustees of Lehigh, they determined to meet the crisis, not with a surrender, but with an advance. The situation of the University, conveniently near to great mining and metallurgical industries, its beautiful grounds and buildings, its efficient corps of instructors, its successful alumni and its acknowledged standing were elements of hope not to be timidly thrown away. What it needed for the mo-

ment was, indeed, to a superficial observer, money; but what it needed for the future as well as the present was a man, capable of commanding and rewarding support—not merely soliciting it; and such a man it found in Thomas M. Drown. As Prof. Talbot well says:

> "He entered upon this new work with exceptional qualifications. He was again among the friends of earlier years; many of these were captains of industry, ready to receive the engineers which should be trained under his direction; he had given much thought, while in Boston, to the sort of training which such young men should have; and his interest in and sympathy with young men was exceptionally strong. It is perhaps too early to adequately measure all that his administration has meant and will mean to the University, but it is certain that it at least has been characterized by an increase in attendance, a broadening of the curriculum in such a way as to recognize the importance of general and culture studies in the education of engineers, and by a perfection of the details of the administration offices of the University. These are, however, but the exterior indications of success. There has been another, and deeper, benefit derived by the students to whose interests he gave not only his time and energies while at his office, but to whom, with the hearty co-operation of Mrs. Drown, he threw open his beautiful home on all occasions of rejoicing, while on Sunday afternoons he regularly visited those detained in the hospital by illness."

It is noteworthy that, although himself ranked as a specialist, he exhibited an intelligent appreciation of other departments than that with which his own career had been most nearly associated. Like the great President of Harvard University, he understood more than chemical analysis and synthesis, and grasped larger problems than those of the laboratory. His interest in educational matters was evinced in many public addresses, full of practical suggestions as well as comprehensive views.

In 1895, Columbia University in the City of New York honored itself, as well as him, by conferring upon him the degree of Doctor of Laws; and his subsequent career fully justified that recognition.

Looking upon the burdens of anxious responsibility, difficult administration and manifold labor which he carried with such cheerful courage, I am impressed with the feeling that the secret of his strength was his unfailing sense of humor. True, he was sustained in every trial by a quiet, deep, strong Christian faith. I, to whom he was like an own brother, cannot conceive of him without that. But he never said much about his religion, and I shall imitate his reticence here. Only, I

must say that I have known many truly religious people to be, with or without their own fault, shadowed with melancholy; and I am sure that the saintliest of pessimists could not have achieved what Drown did, whose religion laughed as well as prayed. He saw the ludicrous side of petty annoyances; he always had a good story to tell; and his bubbling delight in a new one was contagious. Perhaps this gift is inborn only; perhaps (as I fancy) it can be cultivated to an important degree, as well as killed by repression. In either case, blessed are they who have it, as did Luther and Lincoln, together with intellectual strength and serious wisdom. They can carry heavy loads and win great victories, bravely, sanely and with joy!

In nine years of strenuous, dauntless endeavor, President Drown saw the University pass successfully through its most desperate financial straits, advancing all the while, under his calm, inspiring leadership, in the scope and quality of its educational work, and in the extent of its educational plant. He was doubtless looking forward to a period of still greater, though less arduous, advance, when death struck him down at his post of duty.[6]

If he had any premonition of this event, he did not put it into words. Some years before, he had come near to death, and had been saved, when hope seemed gone, by the prompt and skillful action of his surgeon. He told me afterwards that he could not feel secure against a recurrence of the attack; and I fancy that he never recovered full elasticity and endurance, though he certainly showed, in after years, no signs of greater weakness than might naturally be ascribed to growing age. Nor was the final trouble clearly the same as the former. Yet I believe that, during the interval between them, he went on with his work as one who might be called away at any time.

So it came to pass, that, being advised, by reason of certain ominous painful symptoms, to submit to a surgical operation, he made the few preparations necessary to one who had so long

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[6] I am glad to know of the proposal and progress of a movement, in which all the friends of Dr. Drown are co-operating, for the erection at Lehigh University of a Memorial Hall in his honor. That is the proper place and the proper character, for such a memorial; and all those who knew, admired and loved Dr. Drown during earlier periods of his career may well join to make this testimonial, erected in the locality of his last work, a worthy witness to the whole of a beautiful and memorable life.

kept his house in order, bade a cheerful farewell "for a few days" to the members of his household, and walked to the hospital, from which he never returned.

In the combination of gentleness with power, candor with conviction, wide culture with special and accurate knowledge, generosity with judgment, genius with industry, sensitiveness with patience, the keen intellect with the pure heart, the power to win love with the power to command esteem, the wisdom of this world with the wisdom of the world to come, our dear friend stood conspicuous among men. Would there were more like him for us to love, to admire, to imitate, and gratefully to mourn!

Biographical Notice of Bruno Kerl.

BY R. W. RAYMOND, NEW YORK CITY.

(Washington Meeting, May, 1905)

THE death of Privy Councilor Bruno Kerl, on March 25, 1905, terminated a distinguished and useful career.

Bruno Kerl was born March 24, 1824, at St. Andreasberg in the Harz, and entered in 1840 the mining school of Clausthal, where he studied for three years, working at the same time in the mines and stamp-mills. After an additional year of practice in the silver-reduction and iron-works of the Upper Harz, he passed his examination as a metallurgical graduate, and studied for a year at Göttingen under Wöhler in chemistry, Hausmann in mineralogy, and eminent teachers in other branches. In 1846 he was employed at the Oker works, but very soon left this post, to become a tutor in chemistry, metallurgy, etc., at Clausthal, where he continued to labor until 1867. During this period the Clausthal school became a completely equipped Mining Academy, and Kerl was made in 1862 a full professor.

Meanwhile, in addition to the work of instruction, he discharged, simultaneously or successively, the duties of many responsible official positions in the Royal Hanoverian administra-

tion of mines and smelting-works, and also published many valuable books and treatises. Among these were professional guide-books to the Upper and Lower Harz, and their characteristic metallurgical processes; a manual of qualitative and quantitative blow-pipe analysis; another of metallurgical assaying; and, most important of all, a Handbook of Metallurgy in four volumes, the second edition of which was issued in Leipzig, 1861–1865. This book was speedily recognized as the leading authority in its field. In this country, the English translation and revision, by Crookes and Röhrig, published about 1869, had a large circulation.

In addition to these literary labors, Prof. Kerl became in 1859 (and continued to be until 1897) an associate editor of the "Berg-und Hüttenmännische Zeitung," which owes no small part of its fame as a professional classic to his aid and direction.

These activities, together with his high reputation as an instructor and adviser, led to his appointment, in 1867, as professor of metallurgy, technical chemistry, and assaying in the Royal Prussian Mining Academy at Berlin. This position he occupied (with some variation of its specific sphere) until the latter part of 1897, when he retired from active duties and occupations.

Shortly after this distinction was conferred upon him, his native kingdom of Hanover ceased to exist. But science knows no political boundaries; and his services were required in administrative lines by the royal Prussian, and the Imperial German governments. From 1868 to 1892 he was a member of the Board of Manufacturing Industry in the Ministry of Commerce, and from 1877 to 1885 an official of the Imperial Patent Office. In 1889, the title of Privy Mining Councilor ("Geheimer Bergrath"), almost the last of a long series of orders and distinctions,[1] was conferred upon him.

His literary activity was continued in this new and larger sphere. Among the subjects treated by him in publications later than 1867 were: Advances in Metallurgical Assaying; Outline of the Salt-Manufacture; Handbook of the Clay Industry; and compact Manuals of general metallurgy, the

[1] Besides the usual official promotions of the Hanoverian and Prussian civil services, he received knighthood in Hanoverian and Italian orders; and, upon his retirement in 1897, the "Red Eagle" of Prussia.

metallurgy of metals, the metallurgy of iron and steel, and assaying. He also co-operated in the preparation of a German version of Muspratt's great work on technical chemistry; and, from 1871 to 1881, he issued annually a valuable Repertorium of Technical Literature.

His retirement in 1897, by reason of complete failure of health, was practically the end of his career; and his quiet and painless death, on March 25, 1905, at Gross-Lichterfelde, near Berlin, terminated a period of enforced inactivity and of suffering patiently borne.

In 1890, Prof. Kerl was elected an Honorary Member of the Institute, and received this distinction with gratitude and pride. The onerous duties which he was already beginning to lay down, one by one, with advancing age, prevented him from contributing to our *Transactions;* but, long after he had ceased to be able to write with his own hand, and not long before death brought him release, he dictated a letter to the Secretary of the Institute, expressing once more his sympathetic admiration of its work.

Biographical Notice of Benjamin West Frazier, Jr., D.Sc.

BY EDWARD H. WILLIAMS, JR., WOODSTOCK, VT.

(Washington Meeting, May, 1905)

In the middle of the eighteenth century John Frazier and wife, Sarah Ingraham, removed from Boston, Mass., to Philadelphia, Pa., where he was held in such esteem that we find him one of the Committee which arranged the ball at Washington's inauguration. Their son, John Nalbro Frazier, was prosperous in his mercantile career and fortunate in his wife, Anne West, who was an important personage in the early life of Professor Frazier. This cultured lady brought into the family an atmosphere of religious enthusiasm, of thoroughness and of unity of purpose. Her son, Benjamin West Frazier, inherited her traits and displayed them during a short and active life. Like his father, he engaged in mercantile pursuits, and was a member of the firm of Zimmerman, Frazier & Co. In their interests he lived for a short time in Montevideo, and on

BENJAMIN WEST FRAZIER, JR., D.Sc.

his return married Isabella Zimmerman, a daughter of the head of the firm. Their happy married life was cut short by the death of Mrs. Frazier shortly after the birth of the subject of this sketch which occurred October 3, 1841. Mr. Frazier did not long survive her, and left his orphaned sons to the care of his mother, from whom he had inherited a lovable and deeply religious nature, an artistic temperament and a capacity for thorough work. Whatever of these traits fell by inheritance to these children were strengthened by the influence of their grandmother, and the purity of mind, the delicacy of sentiment, the refinement of honor, which characterized Professor Frazier, are due to Anne West Frazier, and are generally present in the characters of all of gentle blood who have been under the sole and immediate influence of a mature and refined woman.

Professor Frazier was educated at the Episcopal Academy in Philadelphia, and passed thence through the University of Pennsylvania, where he was graduated with distinction in 1859, and took his master's degree in 1862. These dates show that his mind matured early, as it was not common for youths of seventeen to receive the bachelor's degree, or to become masters before twenty-one. In this case the precocity was fortunate, as his grandmother died during the year of his graduation and left him, in his eighteenth year, to guide his own steps.

Like his ancestors, he entered upon a mercantile career. He continued in business until 1871, with two intermissions,—the first, a brief one, during his twenty-first year, when he went with one of the volunteer batteries to oppose the march of Lee. After Gettysburg, he joined the City Troop of Philadelphia and retained membership in this famous corps till the second and longer intermission in his business life occurred. In 1866 he married Miss Alice Clark of New York and passed the two following years in Europe; first at the École des Mines in Paris, and later at Heidelberg and Freiberg. In 1871 the leaven of his life worked strongly within him, and he left business to accept the chair of Mining and Metallurgy at Lehigh University; to create there the famous course in mining engineering which has gained for that institution a large portion of its well-earned fame; to pass his life there, impressing upon thousands of young men the beauty of a character dominated by self-de-

votion, absolute truth and justice to all, a high ideal, unquestionable integrity, and thoroughness and pains-taking diligence, combined with an almost womanly modesty and diffidence in exhibiting his splendid attainments. There he displayed the perfection of the art of teaching, and there he died at his home on the campus at South Bethlehem, Pa., January 4, 1905, sincerely mourned by all who knew him; without an enemy; without a successor.

Before 1871 Lehigh University was "finding itself," attracting its students, educating its preparatory schools. During the previous five years of its existence, its courses were modified at will to suit the needs of ill-prepared students. At the expiration of that period, the limits and wants of its courses were apparent, and the preparatory schools had been impressed with the quality of the entrance-work demanded, so that Professor Frazier entered upon his work at a time favorable to progress. Lehigh, though, unlike the majority of colleges, amply endowed, had in 1871 but a limited, yet select, force of high-grade men, who filled its chairs and taught with such thoroughness the small classes that then obtained, that Lehigh graduates at once impressed their qualities on all who came in touch with them.

With Professor Frazier there came to Lehigh new incumbents in the chairs of mathematics and physics, and in the interests of the University they created a new curriculum which, with slight changes, remained for a decade, and was then amplified to meet new requirements. This bald statement of the creation of a curriculum epitomizes many tentative courses of study, and many modifications to meet the small teaching-force of the University, and the standards of preparation offered by entering students. The head of a department seldom had an assistant. When Professor Frazier accepted the chair of Mining and Metallurgy he was expected to teach without assistance geology, mineralogy, crystallography, blowpiping, mining and metallurgy; whatever was required in the courses of civil, mechanical or mining engineering and chemistry. Under geology were included lithology and economic geology; under mining, ore-dressing; under metallurgy, a study of fuels and their valuation,—constituting a total which no one would now think of undertaking. He wisely determined to have nothing to do with geology, and this subject was afterwards taught by

Dr. James P. Kimball. All the remaining subjects were exhaustively taught by him for ten years without assistance.

In arranging his new courses in 1871 he followed a fixed plan by which each study formed the foundation upon which the following one was developed. In carrying out the plan he omitted every thought of self, or of the drudgery and the magnitude of the task, and merely considered the time necessary for the perfect development of each subject. When complete he presented his work to the faculty for its approval, and it was then seen that the work outlined would require a great portion of each week for three and one-half years. It began with crystallography which led to crystal-projection according to the latest methods and a laboratory period of determination from models and natural specimens. Then followed descriptive and determinative mineralogy; qualitative and quantitative blowpiping; descriptive and determinative (megascopic) lithology; economic geology, with a study of ores, fuels and fluxes; mining; ore-dressing; metallurgy—the last alone requiring an average of four hours per week during one year. Every subject was illustrated by a long period of laboratory-work, or by frequent visits to mines, dressing-works, furnaces, forges,—as the case required,—all under the eye of Professor Frazier.

It is fortunate that the classes were small; for, during the first term of each year four classes came to his rooms daily in one or another of these subjects and were thoroughly taught. What this implies can be understood by the teacher or the engineer. Those not conversant with the subjects can appreciate the fact that to cover all this ground would take the greater part of each day during each week of the term and demand great bodily strength to carry it through, and greater mental vigor and elasticity to repeat it with equal thoroughness year after year. They cannot, however, appreciate the conditions under which the subjects were taught, and a review of the condition of technical education, as it bears upon mining engineering, must be made for the first decade of Professor Frazier's work, as well as the changes that modified it subsequently.

Mining engineering is an old-world occupation, and its textbooks were then written in Latin, French, German—only occasionally in English. Whoever taught any of its branches must have had a command of these languages. If he were fortunate,

he was furnished with classes who had a smattering of some of them sufficient to allow them to read a text-book or work of reference with some degree of certainty. Generally, however, the teacher was compelled to translate or adapt a foreign text-book to the needs of the class. The lack of suitable text-books forced Professor Frazier to arrange lecture-courses in crystallography, ore-dressing, mining and metallurgy, which were maintained throughout his work in those subjects. In a few cases he was able to use English text-books for side reference. With the growth of each science, these lecture-notes were amplified, adapted or re-written, as the case required, for ten years.

In 1881 a new chair was created; and mining, ore-dressing, economic geology and lithology were taken from Professor Frazier's shoulders. The relief, however, was but slight; for the classes had so increased in numbers that two or three sections were required for each laboratory-period, and metallurgy developed so rapidly that no text-book could keep pace with any one of its many divisions, and no set of lecture-notes would be adequate during the year after their compilation. Professor Frazier, therefore, arranged a body of notes to cover the fundamental points of each subject, and thus to be available year after year. The amplification and application of each subject; the methods of varying practice; the costs; the comparative efficiencies; the cases illustrating failure, were varied to suit the times and illustrated by excerpts from whatever was newest and most approved—excerpts which were selected by a wide range of reading and digestion of all that appeared in the technical journals of England, France, Germany and Sweden. The students who sat at the feet of Professor Frazier can readily recall the table in his study in the metallurgical building, or the broad desk extending across the lecture-room—both crowded and piled with marked copies of the many books to be used in the coming lecture, and can appreciate the amount of time required to locate and adapt the many quotations with which the skeleton of the lecture-notes was clothed, as well as the ability which introduced them felicitously and fastened them in their place. There was nothing of the patchwork-quilt in the lecture; it was a logically-digested whole which moved in an orderly manner from premises to conclusions.

It was not in his lectures, however, that Professor Frazier

excelled. They served merely to show the magnitude of the ground covered, and the thoroughness with which a wearisome task was performed. It was when the lecture-course was completed and the text-book closed that the great teacher appeared. As he set a most lofty ideal for his own work, so he required his pupils to follow him wherever he led. If the previous work of the class presupposed a working-knowledge of any subject, he assumed that such a knowledge existed, and called upon each one to demonstrate his ability by actual practice, with the result that his colleagues felt that their work was under review, and his courses of work were anticipated with terror and completed with rejoicing. He had a happy faculty of analysis and description, and an equally happy and uncommon ability to impart information by sharp questioning. In entering upon laboratory-work in crystallography, lithology, mineralogy or blowpiping, the classes were divided into small and easily handled squads which worked for one or two hours under his immediate supervision. He would pass from one to another, explain and question until the subject under discussion was fully grasped. There were no bounds to his reviewing. The whole of the past work must be at hand for instant reference or comparison; physical and chemical properties must be memorized and ready for use. Thus, after a term of accurate description, searching and luminous analysis, criticism and comparison, he finished with an equally searching examination which extended over a number of hours. As his standard of work was high, his term-marks were usually much below those given for similarly good work elsewhere; and both faculty and students were sure that each one whom he presented as qualified for graduation had mastered his subject.

In the short and infrequent intervals between tasks he found time to prepare several papers on metallurgical topics—to be noted later. He also began a work on general metallurgy and had brought it to the point where it was announced for publication, when several important discoveries in iron metallurgy seemed to his critical judgment to make the book antiquated. An ordinary author would have rushed it through the press and immediately announced a second and improved edition; but the determination to be accurate and up-to-date compelled Professor Frazier to withdraw the work, and, before it could

be modified, the rapid progress of the science led him to destroy it, to the great regret of all who knew of the matter.

There is another side to the character of Professor Frazier which is little known and is recorded only in the infrequent minutes scattered through the records of the faculty of the University. Coming as he did when Lehigh was creating its permanent courses of study, and was formulating its standards of work and discipline, his influence was ever towards the maintenance of high ideals; the securing of quality rather than quantity in its work. He was an admirable disciplinarian, because he was an innate gentleman. Whatever he planned was carried out quietly; but underneath that quiet and simple statement each one recognized the force and determination of the speaker. His classes were treated with uniform courtesy. There was no favoritism and each had his full measure of attention in listening and responding to questions; of patience in bearing with slow perceptions; of earnestness in reiterating important points. The work was so absorbing and the attention so fully occupied that disorder was never for a moment thought of; and among the many minutes in the faculty records there is not one which notes the remissness of a student in his rooms.

It is too often the case that a member of a faculty gains a false popularity by being the easy-going friend of all in trouble —one who is in favor of remitting all penalties and relaxing all discipline, till rules are looked upon as things to be broken with impunity. Here Professor Frazier was prominent as both a friend of the student and a maintainer of the University standards. He studied the men under his charge, their characters, the quality of their work, their willingness to learn, their handicaps; so that he was fully prepared in each case of failure to advocate or oppose clemency. His colleagues referred the question to his judgment and waited for his summary, which they at once adopted. All who were worthy were granted another chance to pass their examinations with, or without, extra work. In the latter case it meant that the teacher should take from his small share of leisure, and sit by that student till he had mastered the task. It is not to be wondered that the rising of Professor Frazier to respond to a toast in a meeting of Lehigh men should be the signal for heartfelt applause.

For many years he was an important member of the committee on post-graduate work, and its chairman. Here he demanded high-grade work and here he allotted, discussed and valued that work and passed only what was up to the determined standard. In all of these positions, as teacher, disciplinarian, critic, his influence was impressed on Lehigh University so thoroughly that it never can be eradicated.

He early became a member of this Institute, and his work therein is most fitly told by Dr. Raymond, who writes me as follows:

"The American Institute of Mining Engineers was organized in May, 1871. In November of the same year, Prof. Frazier was elected a member. In 1874, and again in 1878, he was elected for the term of three years a Manager—the year intervening between these two terms being dictated by the Rules, which made him ineligible for immediate re-election. The six years of his service fell in what was perhaps the most critical period of the Institute's history—a period during which its rapid growth required of its governing body not merely the conduct of immediate affairs, but also the settlement of innumerable details of plan and method with reference to an unknown future In those days the Institute was not incorporated (indeed it was never incorporated until 1905); the financial responsibility for all measures looking to an expected larger membership was necessarily taken by the Council; and, moreover, the style and manner of its publications had to be boldly, as well as prudently, decided. In this direction, as I have had occasion to say elsewhere,[1] our Secretary, the late Prof. T. M. Drown, took the leading part, but I happen to know personally how freely he received, and how highly he valued, the loyal support and wise advice of Prof. Frazier.

"His contributions to our *Transactions*,[2] though comparatively few, and confined to the earlier period of his membership, were most timely and valuable at a period when our membership consisted largely of bright young adventurers in the field of science, who did not exactly know what had been done by their predecessors, what had been conclusively shown to be impossible, or by what conclusive tests the limits of the possible could be determined. His thorough knowledge of mathematics ('the one science which draws necessary conclusions'), as applied to thermo-dynamics and other fields of mechanics, was both a revelation and a restraint to those of his colleagues who were inclined to invade, with indiscriminate American enthusiasm, the domain of the hitherto unachieved.

"But Prof. Frazier's contributions to our *Transactions* do not begin to indicate the wide range of his knowledge, as it was made known to us in another way. Namely, while Dr. Drown was Secretary of the Institute, a Publication Committee, of which Prof. Frazier was a member, was appointed to advise the Secretary

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[1] On many occasions, but finally in my Biographical Notice of Thomas M. Drown, read May 2, 1905, at the Washington meeting of the Institute.

[2] The Compression of Air (ii., 43); Economy of Fuel in our Anthracite Blast-Furnaces (iii., 157); Remarks on the Nomenclature of Iron and Steel (iv., 338; v., 314); The Mechanical Work Performed in Heating the Blast (vi., 313); Chimney-Draught (x., 249).

and the Council concerning papers offered for publication. In the discharge of this function, as well as by other evidences, Prof. Frazier impressed himself upon Dr. Drown as singularly well-grounded, well-read and accomplished throughout a wide range of scientific and professional subjects. 'One of the best all-round men in the Institute,' was the phrase by which Drown described him to me. My own less frequent intercourse with him confirmed this estimate of his extensive and accurate knowledge."

Besides being a member of this Institute, he was a member of the American Philosophical Society and a Fellow of the American Association for the Advancement of Science. In 1897 his Alma Mater recognized his work and honored herself by conferring upon him the degree of Doctor of Science.

He was prominent in church work, and for many years served as vestryman, teacher in the Sunday-school, and member of the choir. His influence was always for the right, and his conversation free from everything which tended to weaken or make light of our highest ideals. His home life was entirely distinct from his work. His profession was dropped when he left his study; and his family were unaware that he had ever written a technical paper or compiled a book. Outside of the University he developed a disposition which prevented the world from seeing his admirable character; his cultured mind; his wide range in literature and the arts. Fearless in demanding respect and regard for the rules of the University; the conduct of studies; the discipline and courtesy of the class-room; the standards of scholarship and morality, he was exceptionally modest and even diffident in bringing forward his own opinions. Had he possessed a tithe of the confidence of the average man, his splendid attainments would not now be known only to his few intimates in this Institute, to his colleagues in the Lehigh faculty, and to his students. His enduring monument is seen in those students, and the inscription, written broadly so that all may read, is composed of their good work and the high rank they have uniformly taken in their profession.

The Application of Dry-Air Blast to the Manufacture of Iron—Supplementary Data.

BY JAMES GAYLEY, NEW YORK CITY.

(Presented at the Washington meeting, May 3, 1905, and simultaneously sent to the Iron and Steel Institute, for presentation at the meeting of that Society in London, May 11, 1905.)

It is to be regretted that the data respecting the use of dry-air blast, which were presented to the Iron and Steel Institute at its meeting in the United States, in October, 1904, should have been restricted to the period from August 25th to September 9th inclusive, and from September 17th to 30th inclusive. In order to present the paper at all it was found necessary to limit the record of operations to the period above stated. It appears from the reported discussion that some of those who took part felt themselves to be at a disadvantage, in considering the economies secured through the use of dry-air blast, by reason of the fact that the data presented covered so short a period. It is the purpose of this communication to present in detail the record of operations of the Isabella Furnaces from November, 1904, to March, 1905, inclusive, as shown by the furnace-records.

The month of October, 1904, is not included, as the furnace using dry-air blast was stopped several times for repairs; and while the record was a very good one considering these interruptions, yet it was not a continuous one.

The record for Furnace No. 1 using dry-air blast, and the comparison with Furnace No. 3 using natural air for the month of November, 1904, is set forth in Table I.

By a reference to my former paper it will be noted that the month of November is the beginning in this country of the winter period, when the atmosphere decreases rapidly in humidity. The month of October being the transition month in the autumn and April in the spring, and furnaces using natural air approach more closely, from November on, to the conditions obtained by the use of dry-air blast. The data given in

TABLE I.—*Comparison of Records of Furnace No.* 1 *Using Dry-Air Blast and Furnace No.* 3 *Using Natural-Air Blast, November*, 1904.

Year 1904	Grains of Moisture Per Cubic Foot of Air. In Atmosphere		In Dry Blast		Temperature Degrees Fahrenheit. Atmosphere		Dry Blast		Gas Analysis Volumes.	
	Day	Night	Day	Night.	Day.	Night	Day	Night	CO.	CO_2.
Nov. 1....	2.53	2.74	1.15	1.05	51	47	20	17	25.8	12.6
2..	2.82	2.75	1.10	1.02	50	50	18	16	25.6	12 2
3 .	2.64	2.59	1.05	1.01	47	45	16	16	23.6	14.0
4...	2.18	2.44	1.06	1.07	52	50	16	19	23 0	15 0
5...	2.58	1.98	1.13	1.01	54	44	17	19	....	....
6...	1.69	1.79	0.94	1.06	45	44	15	19	....	....
7..	1.86	2.35	1.05	1.04	43	41	17	20	22.8	14 0
8...	2.42	2.43	1.04	1.04	45	44	20	20	....	......
9 .	2.30	2.39	1.09	1.02	46	42	19	19	....	......
10...	2.52	2.49	1 07	1 05	44	45	19	20	22.8	14 0
11...	1.69	1.68	1 00	1.04	44	39	18	20	....	....
12...	1.50	1.73	1.07	1.02	42	47	20	22	....	....
13...	1 88	1.79	1.04	1.00	43	44	21	22	....	....
14	1.56	1 59	1.04	0 95	44	41	20	21	23 8	13.8
15..	1.89	1.91	1.07	1 06	45	45	20	22	....	....
16. .	2.01	1.91	1.11	1.02	49	39	20	21	20.6	13 0
17 .	1.74	1 85	1.01	1.05	41	39	18	22	....	.....
18..	2 04	2.25	1.13	1.09	48	48	21	22	23.4	14.0
19...	2.24	2.35	1.10	1.09	48	50	21	22	....	......
20...	2 74	3.03	1.16	1.04	59	59	22	20	....	......
21...	1 96	1.85	0.98	0 96	52	39	18	20	23.2	16.0
22..	2 06	2.02	1 05	1.03	43	40	20	20	....	....
23..	2 21	2.18	1 03	1 01	44	51	20	21	24 0	12.0
24..	2.43	1.81	1.07	1.00	48	44	21	21	....	....
25 .	1.62	1.32	0.94	0.99	43	44	22	21	24.8	12 0
26...	1.49	1 43	0.98	1.01	39	35	20	21	....	......
27..	1.01	0 90	0.93	0.81	33	29	19	17	....	....
28..	0.88	1 02	0.81	0.83	31	37	18	18	22.6	15 0
29..	2.33	2.30	1 07	1.03	56	49	21	20	....	.....
30...	1.05	1.00	0.81	0.82	37	33	17	18	23.0	15.0
Average..	1.99	1 99	1.03	1.01	46	43	19	20	23.5	13.8

The record of operations is as follows:

	Average Daily Product.	Average Coke-Consumption.	Blowing-Engines.	Average Temp. Hot Blast
	Tons (2,240 lb).	Pounds	Rev per Minute	Degrees Fahrenheit.
No. 1 Furnace: Dry blast...	447	1,816	96	854
No. 3 Furnace: Normal blast	386	2,279	111	750

Table I., with reference to grains of moisture and temperature, represents the average for the day of observations taken hourly during the period indicated.

The temperature of the dry blast is from observations taken at the top of refrigerating-chamber, but this temperature is increased in the passage of the air from the refrigerating-chamber to the blowing-engines.

Table II. shows the record of operations for the month of December, 1904, in which it is interesting to note the decrease in moisture as compared with November. In November the average moisture was 1.99 grains, while in December it was 1.44 grains, the maximum variation, however, being from 0.55 to 3.91 grains.

TABLE II.—*Record of Operations During December*, 1904.

Year 1904	Grains of Moisture Per Cubic Foot of Air.				Temperature Degrees Fahrenheit.				Gas Analysis Volumes	
	In Atmosphere		In Dry Blast.		Atmosphere		Dry Blast			
	Day	Night.	Day	Night.	Day.	Night	Day	Night	CO	CO_2.
Dec 1 .	1.13	1.37	0.98	1.07	35	36	20	21	23.4	13.6
2..	1.41	1.56	1.08	0 97	38	37	20	20	....	......
3...	1 56	1.46	1.02	0 96	35	34	20	20	....	......
4 ..	1 26	1.30	0.99	0 97	33	29	19	19	23.0	14 0
5 .	1.34	1 39	0 97	0.98	31	36	18	20	23 0	14 0
6..	1.28	1.50	1.00	1.00	35	36	20	20	25.0	12 0
7...	1.70	1.67	1.10	0 99	39	40	20	20	......	......
8..	1.31	1.20	1.00	0.95	41	34	20	19	22.6	14.8
9 ..	1.12	1.11	0.93	0.85	32	29	18	18	24.8	14.4
10 ..	0 91	0.55	0.76	0.52	25	15	16	11	24.0	14.0
11..	0.55	0.80	0.43	0 44	15	23	7	10	....	......
12...	1.26	1.37	0 85	0.94	30	30	17	19	24.4	12.8
13 ..	1 04	0.83	0.93	0.64	29	23	18	14	23.0	13.6
14...	0.73	0.64	0.67	0.53	22	13	12	9	24.0	14.0
15 ..	0.74	0.78	0.53	0.56	22	20	8	10	....	......
16...	0 79	0 99	0.72	0.70	20	21	10	11	23.0	15.0
17. .	1 39	1.65	0.79	1.02	29	34	14	20	....	......
18..	1.37	1.72	1 00	1.06	32	32	19	20	....	......
19...	1.81	1.35	1.11	0.96	35	31	21	18	22.3	15 0
20..	1 29	1 31	1.02	1.04	31	34	18	19	22.8	13 4
21...	1.34	1.27	1.07	1.00	31	30	19	18	22.4	13.6
22...	1.23	1.91	1.10	1.08	35	49	19	20	22.6	14.4
23...	2.44	3.50	1.35	1 54	53	53	23	27	....	......
2 ...	2.15	1.71	1.18	0.94	40	35	21	18	23.1	13.2
25 .	2.19	2.31	0.96	1.03	37	38	17	19	....	. .
26 ..	2.37	3.06	1.11	1 25	41	46	19	22	....	......
27...	3.91	2.23	1.41	1.11	58	48	24	21	....	......
28...	0.68	0.72	0.74	0.60	25	21	15	13	24 7	13.3
29...	0.82	0.94	0.67	0.69	25	29	13	13	24.2	13.0
30...	1 04	1.26	0 82	0.91	38	43	15	16	24.8	13.6
31...	1 55	2 22	0 96	1.11	47	51	19	22	....	......
Average..	1.41	1.47	0.94	0.92	34	33	17	18	23.5	13.8

There is also a slight reduction in the grains of moisture in the dry air.

The air conduit-pipe from the refrigerating-chamber to the blowing-engine room was constructed to connect with four blowing-engines, and as only three engines were used on Furnace No. 1, it was decided to connect the fourth engine with the dry-air conduit and apply it to Furnace No. 3, thus making, on No. 3, two engines with natural air and one engine with dry air. The comparison of the work of Furnaces No. 1 and No. 3 and the effect of one-third of the engine-revolutions supplying dry air to No. 3 Furnace is shown as follows:

	Average Daily Product	Average Coke-Consumption.	Blowing-Engines	Average Temp. Hot Blast.
	Tons (2,240 lb)	Pounds	Rev per Minute	Degrees Fahrenheit.
No. 1 Furnace (dry blast)...	455	1,823	96	877
No 3 Furnace:				
Dec. 1–22 (normal blast)..	400	2,309	111	785
Dec. 23–31 (⅓ dry blast)...	461	2,140		

Although one-third of the engine-revolutions supplied dry air, yet the weight of dry air was slightly in excess of one-third the total quantity, by reason of the air being denser.

The result shown by the use of such a small quantity of dry air is remarkable, and is greater than was experienced when first applying the dry air to Furnace No. 1 in August. The application of one-third of the engine-revolutions with dry air increased the weight of air delivered to the furnace, and at the same time the average temperature of hot blast increased 20 degrees. The furnace at once began to drive more rapidly and the burden was also increased. There was no deterioration in the grade of metal produced, in fact it was slighty better, as the silicon was higher and sulphur lower than in the preceding part of the month.

In Table III. is set forth the record for January, 1905, wherein is found a further reduction in the humidity of the atmosphere.

On January 10th the dry blast was changed from Furnace No. 1 to Furnace No. 3. Both furnaces were making the same grade of iron for use in the basic open-hearth process. In the exhibit below no account is taken of the period from the 11th

TABLE III.—*Record of Operations During January*, 1905.

Year 1905.	Grains of Moisture Per Cubic Foot of Air.				Temperature. Degrees Fahrenheit.				Gas Analysis. Volumes.	
	In Atmosphere		In Dry Blast.		Atmosphere		Dry Blast.			
	Day	Night.	Day.	Night.	Day.	Night.	Day.	Night.	CO.	CO_2.
Jan. 1...	2.61	2.75	1.19	1.14	53	51	22	20	....	....
2...	3.31	2.19	1.34	0.82	52	41	21	15	....	......
3...	0.98	0.52	0.50	0.45	27	18	9	9	24.8	13.0
4 ..	0.70	0.78	0.58	0.57	20	22	10	10	24.3	13.2
5...	1.09	1.34	0.73	0.78	29	33	13	14	23.0	14.2
6...	1.85	1.96	0.94	0.80	33	35	16	16	24.0	13 0
7...	1.49	1.19	0.81	0.68	32	29	15	14	23.4	13.0
8...	1 00	0.89	0.71	0.70	26	23	13	12	....	....
9..	0.97	1.72	0.69	0.84	25	31	12	15	....	....
10 ..	0.61	0 90	0.58	0.48	21	23	10	7	....	....
11..	1.65	2.89	0.66	0.81	31	45	9	12	....	....
12...	3.05	1.51	1.00	0.66	48	37	15	11	....	......
13...	1.00	0.86	0.68	0.48	31	27	10	8	....	....
14 ..	0.53	0.65	0.49	0.49	17	20	7	8	....	....
15...	0 77	0.63	0.59	0.45	24	19	9	7	....	....
16 ..	0.85	0.95	0.61	0.53	23	28	10	10	....	....
17...	1.08	1.23	0.65	0.64	31	34	12	12	....	....
18...	1.31	1.33	0.75	0.69	36	41	12	13	22.8	14 2
19...	2 05	1 96	0.86	0.86	42	42	15	16	....	....
20 ..	1.67	1.65	0.78	0.64	42	36	13	11	22.6	14 0
21...	1.87	2.15	0.76	0.75	40	39	12	13	....	....
22..	1.43	0 79	0.77	0.48	35	25	13	9	....	.....
23...	0.85	1.20	0.56	0.57	22	26	9	11	23.8	13 8.
24..	1.44	0 97	0.64	0.51	29	23	12	9	....	......
25 ..	0 67	0.42	0.45	0.35	19	12	7	4	23 0	12.8
26...	0.47	0.69	0.38	0 42	15	17	5	6	22.2	13.0
27...	0 94	1.18	0.46	0.53	24	30	7	7	23 8	13.5
28 ..	0 69	0.38	0.50	0.27	23	9	8	2	22.6	14 8
29...	0.47	0.53	0.28	0.36	10	18	—1	3	....	....
30...	0.72	0.72	0.41	0.37	18	15	3	3	23.4	13 6
31...	0.99	1.22	0.50	0.55	22	28	5	8	23.3	13.7
Average..	1.26	1.23	0.67	0.60	29	28	11	10	23.3	13 5

to 14th inclusive, as this period was occupied in adjusting the dry blast and burden to both furnaces. The record of the burden on each furnace shows as follows:

	Weight of Coke in Charge.	Weight of Ore in Charge.
No. 1 Furnace:	Pounds	Pounds
January 1–10 (dry blast), ...	10,200	24,000
January 15–31 (normal blast), ...	10,200	20,200
No. 3 Furnace:		
January 1–10 (normal blast) (extra coke in charge), ...	10,200	20,200
January 15–31 (dry blast), ...	10,200	23,600

During the period from January 1st to 10th, when No. 3 Furnace was on normal blast, there was charged with the regular burden a small quantity of extra coke. This was taken off when the furnace was changed to dry blast, which would make the burden with dry blast for No. 3 Furnace correspond with No. 1 Furnace with dry blast. The result on each furnace, before and after the change in blast had been made, is as follows:

	Average Daily Product.	Average Coke-Consumption	Blowing-Engines.	Average Temp Hot Blast.
	Tons (2,240 lb).	Pounds.	Rev per Minute	Degrees Fahrenheit.
No 1 Furnace:				
January 1–10 (dry blast)	428	1,825	96	869
January 15–31 (normal blast)	414	2,340	111	771
No. 3 Furnace:				
January 1–10 (normal blast)	410	2,351	111	716
January 15–31 (dry blast)	432	1,811	96	802

The ore-mixture on Furnace No. 3 gave a yield in iron 1 per cent. greater than the mixture on Furnace No. 1. The purpose in changing the dry blast from Furnace No. 1 to No. 3 was to determine the economy on another furnace at a time which represented in that locality nearly the minimum of humidity in the atmosphere, the extreme variations being from 0.38 to 3.31 grains, with a monthly average of 1.25 grains of moisture per cu. ft. of air. The response to the application of dry-air blast was prompt and efficient in result, and clearly demonstrated that even at periods when the humidity of the atmosphere was relatively low, substantial economy in fuel could be obtained. As already noted, an important advantage was obtained by keeping the moisture in the air more uniform. Although the atmosphere is much more humid in the summer than in the winter months, yet in the latter the percentage of variation is much greater. A comparison of the average humidity of the several months of the year is misleading as to the effect of such humidity on the operations of a furnace, since such average results do not take into account the wide fluctuations from day to day, and even in the same day. During the past winter in the Pittsburg district, and generally throughout the northern States, there has prevailed a protracted cold season, and since the beginning of our observations there

has been no winter season showing a lower average of humidity than the one just ended; therefore, under these conditions, any demonstration of the efficiency of dry-air blast, in comparison with a furnace using normal blast, is made at a time when the furnace operated with normal blast is at its highest efficiency.

It has been thought by some that the use of dry-air blast might be dispensed with in the winter months, when the content of moisture in the atmosphere is very low. There could scarcely be a month more favorable to the study of the effect of dry air than that presented in the month of February, 1905, where the average of moisture is 1.19 grains for the daytime, and 1.17 grains for the night, with a maximum variation of from 0.30 to 2.57 grains of moisture per cu. ft. of air. Table IV. shows the record for that month, and it will be noted that

Table IV.—*Record of Operations During February*, 1905.

Year 1905	Grains of Moisture Per Cubic Foot of Air				Temperature. Degrees Fahrenheit				Gas Analysis Volumes	
	In Atmosphere		In Dry Blast		Atmosphere		Dry Blast			
	Day	Night	Day	Night	Day	Night	Day	Night.	CO.	CO_2
Feb. 1...	1.33	0.73	0.71	0.47	30	21	10	7	23 6	13.4
2 .	0.39	0.30	0.35	0.18	13	7	3	—1	....	....
3..	0.48	0.39	0.31	0.22	9	9	1	1	23 8	13.4
4...	0.58	0.49	0.39	0.28	16	14	3	4	....	....
5 .	0 73	1 64	0.41	0.63	20	31	6	11	....	....
6..	1.66	0.79	0 71	0 49	34	23	13	7	24.0	13.0
7 .	0.69	0.67	0.51	0 35	23	16	7	3	....	....
8	0 79	2.27	0.42	0.80	26	39	4	14	23.6	14 0
9...	2.57	1.67	0.95	0.78	43	37	16	13	23.4	14 0
10 .	1 02	0.61	0 83	0 46	30	20	13	17	....	....
11 .	0.60	1 04	0 56	0.52	18	30	6	9	....	.. .
12..	2.25	2.01	0 87	0.81	37	37	12	13	....	....
13..	0.72	0.40	0 64	0 28	20	9	9	2	24.6	13 4
14 .	0.40	0 71	0.37	0.35	8	21	0	5	....	....
15..	0.45	0.32	0.48	0.24	16	9	3	2	....	. .
16...	0 53	0.73	0.35	0.33	15	27	2	4	23.6	12 2
17..	1.04	0 84	0.61	0 48	33	27	9	6	24.0	14 2
18..	0 73	0 68	0.55	0.39	25	24	6	4	. ...	.. ...
19..	0.87	1.15	0 51	0.60	27	32	5	9	.. ..	.....
20..	1.98	2.06	0.86	0.97	39	41	12	13	....	......
21...	1.56	2.11	0 71	0.88	38	37	14	10	25.6	12 4
22...	2.37	2.01	1.02	0.86	40	38	12	10	....	....
23 .	1.86	1.69	1.11	0.74	28	36	13	9	24.0	14.0
24...	1.70	1 65	0.88	0.70	37	32	9	8	22.0	15 0
25. .	1.77	2.10	0.91	0.88	34	40	10	10	....	......
26...	1.48	0.91	0 90	0 43	38	28	13	5	....	....
27...	0.97	1.34	0.70	0.53	29	35	8	10	....	....
28...	1.74	1.40	0.62	0.59	40	37	8	7	25.6	12.2
Average..	1.19	1.17	0.65	0.54	28	27	8	8	23.9	13.4

during several days the average moisture-content of the atmosphere is lower than the average for the month in the dry blast.

The record of operations is as follows:

	Average Daily Product	Average Coke-Consumption	Blowing-Engines.	Average Temp. Hot Blast.
	Tons (2 240 lb)	Pounds.	Rev per Minute.	Degrees Fahrenheit.
No. 1 Furnace (normal blast).	424	2,248	111	800
No. 3 Furnace (dry blast)......	412	1,815	96	784

As already pointed out, the benefits derivable from the use of dry air can be directed, in the main, to increase of production, or to decrease in coke-consumption, or to both purposes. In the month of February, by reason of the dry atmosphere and the large volume of air on Furnace No. 1, the operations at Furnace No. 3 were directed principally toward economy in coke. The output of Furnace No. 3 is less than of No. 1, as the former was stopped several times during the month on account of break-downs of slag-machine, and break-outs of iron at the hearth. Notwithstanding the low content of moisture in the normal blast which represented conditions rarely obtained in that district, the furnace supplied with dry blast made, considering the stops, practically as much iron—with a consumption of coke 433 lb. less per ton of iron—as the furnace supplied with normal blast. As the summer season approaches, the product of the furnace using normal blast will steadily decrease and the fuel increase, while the work of the furnace supplied with dry air will continue practically uniform. It is doubtful if a better illustration can be had than that offered by the month of February in demonstrating the value of maintaining the blast practically uniform as to dryness.

As will be seen by Table V. the advent of the spring months makes a material increase in the moisture. The operations in March were seriously interrupted by reason of high water in the Allegheny river, which flooded the works, and caused a shut-down of several days. On account of this shut-down, extra charges of fuel were added to both furnaces. On starting the plant, Furnace No. 3, supplied with dry air, responded more quickly, and reached the normal grade of iron in one day, while it required three days to obtain like results on Furnace No. 1. The record for the month is set forth in Table V.

TABLE V.—*Record of Operations During March*, 1905.

Year 1905	Grains of Moisture Per Cubic Foot of Air.				Temperature Degrees Fahrenheit.				Gas Analysis. Volumes.	
	In Atmosphere		In Dry Blast		Atmosphere.		Dry Blast.			
	Day.	Night	Day.	Night	Day	Night.	Day	Night.	CO.	CO_2
Mch. 1...	1.77	0.78	0.90	0.52	37	27	13	5	....	....
2..	0.78	1.00	0.55	0.44	29	30	4	7	....	....
3..	1.81	2.06	0.74	0.59	37	42	9	10	....	....
4...	1.98	1.16	0 91	0.42	44	31	13	8	....	....
5...	1.60	1.69	0.74	0 69	39	40	11	12	....	....
6...	1.24	1.44	0.75	0.62	38	38	10	10	23 5	14 0
7.	2 28	3.29	0.90	1.04	41	47	13	14	....	....
8..	2.73	1.61	1.07	0 68	44	33	15	9	....	....
9..	1.73	2.19	0.68	0.83	35	41	9	12	....	....
10...	1.94	1.20	0.88	0.60	43	32	14	10	....	....
11.	1.37	1.52	0.75	0.75	39	36	12	11	....	....
12...	1.33	1.09	0.74	0.54	40	32	11	9	....	....
13...	1.00	1.16	0.71	0.64	35	34	10	12	....	....
14...	1.22	1.32	0.81	0 57	36	33	12	10	....	....
15 ..	1.64	1.85	0.85	0.84	39	38	10	13	....	....
16	2.47	2.74	1.11	1.12	49	52	15	18	....	....
17..	2.64	2.74	1.21	1 12	54	53	18	18	23.9	13 5
18	2.85	3 84	1.31	1.38	64	65	21	24	....	....
19 .	4.80	4.08	1.65	1 54	60	61	24	23	....	....
20, 21, 22	Furnace banked on account of high water.									
23.	2.61	2 95	0 81	1.08	52	56	10	15	....	....
24. .	3.32	3.08	1.32	1 15	58	51	21	16	....	....
25	2.69	2 73	1.29	1 09	60	54	18	16	....	....
26 .	3 19	2.93	1.20	1.11	58	58	17	16	....	....
27..	2.34	2 58	1.26	1.19	64	64	18	17	....	....
28..	2.92	4 04	1 29	1.42	66	63	18	23	....	....
29..	3 08	3.16	1.34	1 27	68	68	21	23	....	....
30	3.30	2.18	1.42	0.88	59	49	22	16	....	....
31 .	2 23	2.39	1.21	1.01	57	55	17	15	....	....
Average..	2.25	2.25	1.01	0 89	48	45	14	14	23.7	13 7

The record of operations for the month is as follows:

	Average Daily Product	Average Coke-Consumption.	Blowing-Engines	Average Temp. Hot Blast.
	Tons (2,240 lb)	Pounds	Rev per Minute	Degrees Fahrenheit
No. 1 Furnace (normal blast).	411	2,274	111	850
No. 3 Furnace (dry blast).....	405	1,837	96	784

The product of No. 3 Furnace is a little less than of Furnace No. 1; but No. 3 was banked nearly one day longer than No. 1, which would more than make up the difference.

In the discussion of my paper presented to the Institute in

October, 1904, I note a comparison of the Isabella with the Edgar-Thomson furnaces, without due regard being given to the different conditions existing at these plants. During the period covered in this communication the Edgar-Thomson furnaces workéd with a mixture of ores yielding 55.5 per cent. of iron, while the Isabella mixture yielded but 51.5 per cent. of iron—and in addition the stoves at the Edgar-Thomson gave a temperature from 200 to 300 degrees higher than at the Isabella. The results achieved by the use of dry blast have been from furnaces that might properly be designated as old furnaces; they have been banked several times, which invariably has a deteriorating effect; and the coke charged was an inferior grade from the Connellsville region, and used altogether on furnaces making basic iron.

The data presented in this communication are the furnace records entire for the points covered. In considering them, it should be borne in mind that the reported comparative results of dry blast and normal blast have been obtained under the atmospheric conditions most favorable to the latter.

The Classification of Coals.*

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(Washington Meeting, May, 1905)

Introduction.

Various classes of coals are recognized in this country at the present time. These classes depend largely upon physical characteristics rather than upon chemical composition, and consequently they cannot be accurately defined. The divisions into anthracite, semi-anthracite and semi-bituminous are fairly satisfactory; but the term bituminous embraces so large a variety of coal that it is of little value, and the term lignite is so loosely applied that it has little or no place in a scientific classification.

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At present there is no way of accurately defining the various classes of coal, because no adequate scheme of classification, which applies to lignites as well as bituminous coal and anthracite, has been proposed. The object of this paper is to present such a scheme, which is based upon data obtained during the past year by Prof. N. W. Lord,[1] in charge of the chemical laboratory of the United States Geological Survey coal-testing plant at the Louisiana Purchase Exposition, St. Louis.

All the classifications of coals proposed prior to 1877 were based either on physical characteristics or on proximate analyses including all of the impurities. These schemes are illogical and highly unsatisfactory; for the physical properties of a coal give little indication of its true composition, and impurities, such as ash and sulphur, are largely the results of accidents during the deposition of the coal and not directly related to its fuel-value.

The Pennsylvania Classification.

The first serious attempt in this country to establish a scientific classification was made by Persifor Frazer, Jr., while engaged in work as assistant geologist on the Second Geological Survey of Pennsylvania. The results of his investigations along this line were first presented to the American Institute of Mining Engineers at the Wilkes-Barre meeting,[2] May, 1877. This classification was based on the fuel-ratio, which was described as the quotient of the fixed carbon divided by the volatile combustible matter. Fuel-ratios were calculated for a great many Pennsylvania coals, and, after a careful comparison with the coals themselves, the following classification was adopted:

Classification of Pennsylvania Coals.

	Fuel-Ratios
Anthracite,	100 to 12
Semi-anthracite,	12 to 8
Semi-bituminous,	8 to 5
Bituminous,	5 to 0

[1] For the original analyses upon which this paper is based and for complete description of the coal samples analyzed, see Preliminary Report on the Operations of the Coal-Testing Plant of the United States Geological Survey at the Louisiana Purchase Exposition, St Louis, Mo., 1904, *Bulletin* No 261, *U. S. Geological Survey*. A detailed report of this work is now in press.

[2] *Trans*, vi., 430, also in *Report MM of the Second Geological Survey of Pennsylvania in* 1876–78, p. 128.

This scheme worked very satisfactorily for the Pennsylvania coals, but the selection of the name "semi-bituminous" was unfortunate, since its application is directly at variance with the true meaning of the word.

The great advantage of this scheme over those previously used is that it is based on certain definite constituents of the coal, and these constituents, in a general way, determine the fuel-value of the coal; but when an attempt was made to apply this classification to the various coals of the United States, it was found to be inapplicable.

It failed in two particulars, (1) in grouping all of the coals with a fuel-ratio of 5, or less, into one class, and (2) in making no provision for lignite, which now has become the chief source of fuel in the West.

The failure to define lignite is generally regarded as the more serious defect; but, in my opinion, it is no more serious than to include in one great group all of the bituminous coals of the country. This scheme places the low-grade coals of Iowa and Missouri in the same class, and, inferentially, gives them much the same value as New and Kanawha River coals of West Virginia and the great Pittsburg bed of Pennsylvania—an arrangement which is manifestly unjust, and sufficient to condemn the scheme without reference to the lignites which have no place in the classification, except with the bituminous coals.

Classification of Lignites.

One of the characteristic features of lignite is the large percentage of moisture that it contains; and some geologists have proposed to use this fact as a basis of separation between it and low-grade bituminous coal. Collier[3] proposed a moisture-content of 10 per cent. as the basis of separation between bituminous coal and lignite. According to his scheme, all coals having a percentage of moisture equal to or greater than 10 should be considered lignite, and all those having a percentage less than 10 should be considered bituminous.

The results obtained at St. Louis during the past summer clearly show that this is not a safe basis for a scientific division into these two great classes of coal, for the reason that

[3] Coal Resources of the Yukon, Alaska, *Bulletin No.* 218, *U. S. Geological Survey* (1903)

many of the well-recognized bituminous coals of the Mississippi Valley contain more than 10 per cent. of moisture; and consequently it would be manifestly incorrect to class these coals as as lignite, or even lignitic coal.

The results above referred to show that 3 samples of Illinois coal, 2 samples of Indiana coal, 5 samples of Iowa coal, 2 samples of Missouri coal, and 1 sample of Montana coal contain more than 10 per cent. of moisture in the samples received from the mines, or from the car-load after delivery at St. Louis. Moreover, three of the above-named samples showed more than 10 per cent. of moisture after air-drying until the weight of the sample had become fairly constant. On the other hand, samples of black lignite from New Mexico contained respectively, 9.13, 9.68 and 9.40 per cent. of moisture in samples cut in the mine, and at once sealed in air-tight cans before sending to the laboratory for analysis These facts show conclusively that the moisture-content is not a basis upon which a satisfactory classification can be based.

Other Schemes of Classification.

The analytical work done at the laboratory at St. Louis affords an excellent opportunity for testing the value of various schemes of classification. Proximate and ultimate analyses were made of 56 samples of coal representing the classes of brown lignite, black lignite, low-grade bituminous, high-grade bituminous, semi-bituminous, and anthracite coal.

Fuel-Ratio.

In order to test the possibility of using the various constituents of the coal, determined both by proximate and by ultimate analyses, as a basis for a scheme of classification, several tables have been prepared. Table I. shows the samples classed according to their fuel-ratios (Pennsylvania system):

Table I.—*Classification of Coals According to Fuel-Ratio.*

Name of Sample	Name of Coal-Bed or Field	Fuel-Ratios.
1. Pennsylvania, No. 3,	(Anthracite),	10.22
2. Arkansas, No. 5,	(Spadra bed),	5.75
3. Arkansas, No. 2,	(Huntington bed),	4.53
4. West Virginia, No. 11,	(Pocahontas bed),	4.19

5. West Virginia, No. 12,	(Pocahontas field),	4.12
6. West Virginia, No 10,	(Pocahontas field),	4 04
7. Arkansas, No 1,	(Huntington bed),	3.82
8. West Virginia, No 7,	(New River field),	3.58
9. Arkansas, No. 3,	(Huntington bed),	3.43
10. West Virginia, No 6,	(New River field),	3.34
11. West Virginia, No. 4,	(Upper Freeport bed),	2.16
12. West Virginia, No. 9,	(Kanawha field),	2.12
13. West Virginia, No. 5,	(Upper Freeport bed),	2.05
14. Pennsylvania, No. 4,	(Connellsville field),	2.03
15. West Virginia, No 3,	(Upper Freeport bed),	1.93
16. West Virginia, No 8,	(Kanawha field),	1.83
17. Illinois, No 3,	(Marion county),	1.72
18. Kansas, No. 5,	(Weir-Pittsburg bed),	1.70
19. Alabama, No 1,	(Warrior field),	1.67
20. Alabama, No. 2,	(Warrior field),	1 56
21. Kentucky, No. 1,	(Eastern field),	1.56
22. Kansas, No. 1,	(Weir-Pittsburg bed),	1.51
23. Kansas, No 2,	(Weir-Pittsburg bed),	1 49
24. West Virginia, No 1,	(Pittsburg bed),	1.49
25. Iowa, No. 1,	(Wapello county),	1.47
26. Illinois, No. 6,	(Montgomery county),	1 45
27. Indian Territory, No 1,	(Henryetta bed),	1.40
28. Illinois, No. 4,	(Belleville field),	1 37
29. Iowa, No. 5,	(Lucas county),	1.36
30. Indian Territory, No 2,	(Hartshorne bed),	1.34
31. *New Mexico, No.* 1,	(Black lignite, Gallup field),	1.33
32 Kentucky, No. 4,	(Western field),	1.29
33 Indian Territory, No. 3,	(McAlester bed),	1.28
34. Kansas, No. 4,	(Atchison field),	1 27
35 Kentucky, No. 3,	(Western field),	1 27
36 West Virginia, No 2,	(Pittsburg bed),	1.25
37. Indiana, No 1,	(Sullivan county),	1.22
38. Kentucky, No. 2,	(Western field),	1.19
39. Montana, No 1,	(Red Lodge),	1 17
40. *Colorado, No* 1,	(Black lignite, Boulder field),	1.16
41. Indian Territory, No 4,	(McAlester bed),	1 16
42. Missouri, No. 1,	(Rich Hill field),	1.15
43. Indiana, No. 2,	(Warrick county),	1.14
44 Iowa, No. 2,	(Marion county),	1.13
45. Missouri, No. 2,	(Bevier field),	1 13
46. Iowa, No. 4,	(Appanoose county),	1 11
47. *New Mexico, No.* 2,	(Black lignite, Gallup field),	1 09
48. Illinois, No 1,	(Belleville field),	1.06
49. *North Dakota, No* 2,	(Brown lignite, Williston field),	1 06
50. *Wyoming, No.* 1,	(Black lignite, Sheridan field),	1 05
51. *Texas, No.* 2,	(Brown lignite, Wood county),	1.02
52. Wyoming, No. 2,	(Cambria field),	1 00
53. Missouri, No. 4,	(Morgan county),	0.99
54. Iowa, No. 3,	(Polk county),	0 95
55. *North Dakota, No* 1,	(Brown lignite, Lehigh field),	0.87
56. *Texas, No.* 1,	(Brown lignite, Houston county),	0.68

Table I. shows clearly that the figures denoting fuel-ratio are not satisfactory as a basis of classification. So far as the upper part of the column is concerned, it works perfectly, the anthracite being sharply differentiated from the semi-bituminous coals which follow; but in the lower part of the column there is great confusion, two samples of Pittsburg coal standing No. 24 and No. 36 in the list. Moreover, there is absolutely no indication of a line of separation between bituminous coals and lignites. Hence the conclusion is inevitable; that, for any general scheme of classification applicable to the various grades of coal in this country, fuel-ratios are not adequate and must be discarded.

Fixed Carbon.

With regard to fixed carbon it may be interesting to compare the percentages of fixed carbon, as shown by the proximate analyses, and on this basis Table II. has been prepared, in which the ash and sulphur are classed as impurities, the percentages being obtained by regarding the moisture, volatile combustible matter, and fixed carbon of the air-dried sample as 100 per cent. On this basis the percentages of fixed carbon are as follows:

TABLE II.—*Classification of Coals According to Fixed Carbon.*

Name of Sample	Name of Coal-Bed or Field	Percentage of Fixed Carbon.
Pennsylvania, No 3,	(Anthracite),	88.82
Arkansas, No. 5,	(Spadra bed),	83.95
Arkansas, No. 3,	(Huntington bed),	81.25
West Virginia, No. 11,	(Pocahontas bed),	80.00
West Virginia, No. 12,	(Pocahontas field),	79.94
West Virginia, No. 10.	(Pocahontas field),	79.61
Arkansas, No 1,	(Huntington bed),	78.19
West Virginia, No. 7,	(New River field),	77 56
Arkansas, No. 3,	(Huntington bed),	76.71
West Virginia, No. 6,	(New River field),	76.42
West Virginia, No. 4,	(Upper Freeport bed),	67.57
West Virginia, No 9,	(Kanawha field),	67.24
West Virginia, No 5,	(Upper Freeport bed),	66 77
Pennsylvania, No. 4,	(Connellsville field),	66.55
West Virginia, No 3,	(Upper Freeport bed),	65.14
West Virginia, No. 8,	(Kanawha field),	63 61
Kansas, No. 5,	(Weir-Pittsburg bed),	61 62
Alabama, No. 1,	(Warrior field),	61.49
Kentucky, No 1,	(Eastern field),	59.73
Alabama, No. 2,	(Warrior field),	59.15

West Virginia, No. 1,	(Pittsburg bed),	59.13
Illinois, No. 3,	(Marion county),	59.00
Kansas, No. 2,	(Weir-Pittsburg bed),	58.28
Kansas, No. 1,	(Weir-Pittsburg bed),	57.58
Indian Territory, No. 2,	(Hartshorne bed),	56.15
Indian Territory, No. 1,	(Henryetta bed),	55.84
Iowa, No. 1,	(Wapello county),	55.72
Illinois, No. 6,	(Montgomery county),	55.66
West Virginia, No. 2,	(Pittsburg bed),	54.83
Kentucky, No. 4,	(Western field),	54.79
Indian Territory, No. 3,	(McAlester bed),	53 90
Kansas, No. 4,	(Atchison field),	53.56
Kentucky, No. 3,	(Western field),	52 35
Iowa, No. 5,	(Lucas county),	51.50
Missouri, No. 1,	(Rich Hill field),	51.21
Kentucky, No. 2,	(Western field),	51.06
Indian Territory, No. 4,	(McAlester bed),	50.69
New Mexico, No. 1,	(Black lignite, Gallup field),	50 49
Iowa, No. 2,	(Marion county),	50.28
Illinois, No. 4,	(Belleville field),	50.26
Indiana, No 1,	(Sullivan county),	49.51
Indiana, No 2,	(Warrick county),	49.44
Montana, No. 1,	(Red Lodge),	48.47
Wyoming, No. 2,	(Cambria field),	48.11
Illinois, No. 1,	(Belleville field),	47.61
Missouri, No 2,	(Bevier field),	47.19
Missouri, No. 4,	(Morgan county),	46 97
New Mexico, No. 2,	(Black lignite, Gallup field),	46 83
Iowa, No 4,	(Appanoose county),	46.57
Iowa, No. 3,	(Polk county),	46.16
Colorado, No. 1,	(Black lignite, Boulder field),	45.96
Texas, No. 2,	(Brown lignite, Wood county),	44.47
North Dakota, No 2,	(Brown lignite, Williston field),	42 33
Wyoming, No. 1,	(Black lignite, Sheridan field),	41.55
North Dakota, No. 1,	(Brown lignite, Lehigh field),	38.30
Texas, No. 1,	(Brown lignite, Houston county),	34 06

Since the carbon of coal is its most predominant element, a classification based on the fixed carbon naturally agrees very closely with the fuel-ratios where the volatile combustible matter is small, hence in the upper part of the column the arrangement is fairly satisfactory, but in the lower part, although low-grade bituminous coals occur near the bottom of the series, two of the lignites occur considerably above them, and consequently this classification is not satisfactory.

Calorific Value.

Tables I. and II. show that the data supplied by proximate analyses cannot be used in a scientific classification of coals.

The only other simple classification is based on the calorific values determined in a calorimeter. At the laboratory of the testing-plant these were determined in a Mahler bomb-calorimeter. They have been recalculated on a basis of pure coal, that is, excluding the ash as so much inert matter, and the results are given in the following table:

TABLE III.—*Classification of Coals According to Calorific Value.*

Name of Sample	Name of Coal-Bed or Field	British Thermal Units.
West Virginia, No. 10,	(Pocahontas field),	15,927
West Virginia, No. 12,	(Pocahontas field),	15,833
West Virginia, No. 11,	(Pocahontas bed),	15,786
West Virginia, No. 6,	(New River field),	15,743
West Virginia, No 7,	(New River field),	15,647
Pennsylvania, No. 4,	(Connellsville field),	15,506
Arkansas, No. 3,	(Huntington bed),	15,482
West Virginia, No. 4,	(Upper Freeport bed),	15,440
West Virginia, No. 9,	(Kanawha field),	15,417
Arkansas, No. 2,	(Huntington bed),	15,399
West Virginia, No. 5,	(Upper Freeport bed),	15,396
Arkansas, No. 1,	(Huntington bed),	15,393
West Virginia, No 3,	(Upper Freeport bed),	15,325
West Virginia, No. 8,	(Kanawha field),	15,277
Arkansas, No. 5,	(Spadra bed),	15,270
West Virginia, No. 1,	(Pittsburg bed),	15,129
West Virginia, No 2,	(Pittsburg bed),	15,048
Kentucky, No. 1,	(Eastern field),	14,984
Pennsylvania, No. 3,	(Anthracite),	14,906
Alabama, No 1,	(Warrior field),	14,833
Kansas, No. 5,	(Weir-Pittsburg bed),	14,795
Indian Territory, No 2,	(Hartshorne bed),	14,624
Kansas, No. 2,	(Weir-Pittsburg bed),	14,535
Kentucky, No 4,	(Western field),	14,394
Kansas, No. 1,	(Weir-Pittsburg bed),	14,280
Missouri, No 4,	(Morgan county),	14,276
Alabama, No. 2,	(Warrior field),	14,232
Kansas, No 4,	(Atchison field),	14,120
Indian Territory, No. 1,	(Henryetta bed),	14,076
Indian Territory, No. 3,	(McAlester bed),	14,054
Missouri, No 1,	(Rich Hill field),	13,997
Kentucky, No. 2,	(Western field),	13,836
Kentucky, No. 3,	(Western field),	13,702
Illinois, No. 3,	(Marion county),	13,689
Iowa, No. 1,	(Wapello county),	13,646
Iowa, No. 2,	(Marion county),	13,471
Iowa, No. 3,	(Polk county),	13,443
Indiana, No. 2,	(Warrick county),	13,340
Wyoming, No. 2,	(Cambria field),	13,331

Illinois, No. 1,	(Belleville field),	13,268
Indiana, No. 1,	(Sullivan county),	13,232
Indian Territory, No 4,	(McAlester bed),	13,151
Illinois, No. 6,	(Montgomery county)	13,085
Iowa, No 5,	(Lucas county),	12,711
Iowa, No. 4,	(Appanoose county),	12,683
Missouri, No. 2,	(Bevier field),	12,638
New Mexico, No. 2.	(Black lignite, Gallup field),	12,629
Illinois, No. 4,	(Belleville field),	12,469
New Mexico, No. 1,	(Black lignite, Gallup field),	12,309
Montana, No 1,	(Red Lodge),	12,139
Colorado, No. 1,	(Black lignite, Boulder field),	11,525
North Dakota, No. 1,	(Brown lignite, Lehigh field),	11,465
Texas, No. 1,	(Brown lignite, Houston county),	10,990
Texas, No. 2,	(Brown lignite, Wood county),	10,981
Wyoming, No. 1,	(Black lignite, Sheridan field),	10,876
North Dakota, No. 2,	(Brown lignite, Williston field),	10,174

The results, shown in Table III., are fairly satisfactory, so far as the lower part of the scale is concerned. The lignites are more nearly grouped than in any of the preceding tables; but there is still some uncertainty about the dividing line between them and the bituminous coals. This scheme of classification fails in the upper part, as many of the bituminous coals are of a higher calorific value than the best grades of anthracite.

Hydrogen.

Since the results obtained by proximate analyses and determination of calorific values give no fair basis for classification, recourse must be had to the elements shown in an ultimate analysis. Heretofore, ultimate analyses have not been regarded as important, and few have been made. All coals, however, that were tested at St. Louis during the past season, were analyzed in this manner, and the results afford a mass of fairly satisfactory evidence upon which to base conclusions. In every case the analysis of the air-dried sample is used, and the percentages are recalculated on the basis of excluding ash and sulphur. The classification based on percentages of hydrogen is as follows:

TABLE IV.—*Classification of Coal According to Hydrogen.*

Name of Sample	Name of Coal-Bed or Field.	Percentage of Hydrogen In Water.		Total
Pennsylvania, No 3,	(Anthracite),	0.28	3.11	3.39
Arkansas, No. 5,	(Spadra bed),	0.16	4.20	4.36
West Virginia, No 11,	(Pocahontas bed),	0.10	4.48	4.58
Arkansas, No 2,	(Huntington bed),	0.09	4.56	4.65
Arkansas, No 1,	(Huntington bed),	0.15	4 51	4 66
West Virginia, No. 7,	(New River field),	0.09	4.58	4.67
Arkansas, No 3,	(Huntington bed),	0.10	4.58	4.68
West Virginia, No. 12,	(Pocahontas field),	0.07	4 65	4.72
West Virginia, No. 10,	(Pocahontas field),	0.08	4.75	4 83
West Virginia, No. 6,	(New River field),	0 08	4 91	4 99
West Virginia, No. 4,	(Upper Freeport bed),	0.12	5 23	5.35
West Virginia, No 5,	(Upper Freeport bed),	0.08	5.30	5.38
West Virginia, No 9,	(Kanawha field),	0.12	5.34	5.46
Alabama, No 2,	(Warrior field),	0 33	5.21	5.54
Pennsylvania, No. 4,	(Connellsville field),	0.08	5 46	5.54
West Virginia, No. 3,	(Upper Freeport bed),	0.12	5.42	5 54
Kentucky, No. 4,	(Western field),	0.35	5 27	5.62
West Virginia, No 8,	(Kanawha field),	0.19	5.43	5.62
West Virginia, No. 1,	(Pittsburg bed),	0.16	5.51	5.67
Illinois, No 3,	(Marion county),	0.76	4.92	5.68
Kentucky, No 1,	(Eastern field),	0.22	5.46	5.68
Indian Territory, No. 3,	(McAlester bed),	0.45	5.25	5.70
Alabama, No. 1,	(Warrior field),	0.20	5.53	5 73
Indian Territory, No 2,	(Hartshorne bed),	0.22	5 52	5.74
West Virginia, No 2,	(Pittsburg bed),	0.18	5.57	5 75
Kansas, No. 5,	(Weir-Pittsburg bed),	0 24	5.57	5.81
Indian Territory, No 1,	(Henryetta bed),	0.49	5.37	5.86
Indian Territory, No 4,	(McAlester bed),	0 66	5.20	5.86
Iowa, No 1,	(Wapello county),	0.74	5 14	5 88
Texas, No 2,	(Brown lignite, Wood county),	1 39	4 51	5.90
Kansas, No. 1,	(Weir-Pittsburg bed),	0 50	5 45	5.95
Illinois, No 6,	(Montgomery county),	0 70	5 34	6 04
Montana, No. 1,	(Red Lodge),	1.15	4 89	6 04
North Dakota, No. 2,	(Brown lignite, Williston field),	2.00	4.05	6 05
Kansas, No. 2,	(Weir-Pittsburg bed),	0 33	5.73	6 06
North Dakota, No. 1,	(Brown lignite, Lehigh field),	1 98	4 10	6 08
Kentucky, No. 3,	(Western field),	0 75	5.37	6 12
Kentucky, No 2,	(Western field),	0 69	5.44	6.13
Illinois, No. 4,	(Belleville field),	1 46	4 68	6 14
Wyoming, No 2,	(Cambria field),	0 41	5.76	6.17
Colorado, No 1,	(Black lignite, Boulder field),	1 60	4.58	6.18
Illinois, No 1,	(Belleville field),	0 85	5.36	6.21
New Mexico, No 1,	(Black lignite, Gallup field),	1.31	4.90	6.21
Indiana, No 1,	(Sullivan county),	1.15	5.07	6 22
Iowa, No 2,	(Marion county),	0.61	5.61	6.22
Indiana, No 2,	(Warrick county),	0 85	5 39	6.24
Missouri, No. 1,	(Rich Hill field),	0 52	5 74	6.26

Iowa, No. 4,	(Appanoose county),	1 33	4.99	6.32
Iowa, No. 3,	(Polk county),	0.65	5.70	6.35
New Mexico, No. 2,	(Black lignite, Gallup field),	1 14	5.21	6.35
Kansas, No. 4,	(Atchison field),	0 50	5.87	6 37
Missouri, No 2,	(Bevier field),	1.31	5.10	6.41
Iowa, No. 5,	(Lucas county),	1.23	5.21	6 44
Wyoming, No 1,	(Black lignite, Sheridan field),	2.08	4.36	6.44
Missouri, No 4,	(Morgan county),	0 67	5.79	6.46
Texas, No 1,	(Brown lignite, Houston county),	1.77	4.85	6.62

The results of Table IV. are fairly satisfactory as regards the highly-carbonized coals, but even in this part of the column the difference between the Pennsylvania anthracite and the semi-bituminous coals of Arkansas and West Virginia is not very well marked. The greatest difficulty, however, in using hydrogen as a basis for classification, is in the lower-grades of bituminous coals and lignites. As shown in Table IV., lignites are quite regularly distributed throughout a range of from 5.90 to 6.62 per cent., the lowest in this table. Hence, it is manifest that the percentage of hydrogen present is of no use for the purpose of a proper classification.

Carbon.

Classification according to carbon-content is much better, as shown by Table V.:

TABLE V.—*Classification of Coals According to Carbon.*

Name of Sample	Name of Coal-Bed or Field.	Percentage of Carbon
Pennsylvania, No 3,	(Anthracite),	90.73
West Virginia, No 10,	(Pocahontas field),	90.63
West Virginia, No. 12,	(Pocahontas field),	90 55
Arkansas, No 2,	(Huntington bed),	90.18
Arkansas, No. 5,	(Spadra bed),	90.11
West Virginia, No 11,	(Pocahontas bed),	89.95
West Virginia, No. 6,	(New River field),	88.72
Arkansas, No. 1,	(Huntington bed),	88.16
West Virginia, No. 7,	(New River field),	87.95
Arkansas, No 3,	(Huntington bed),	87.89
Pennsylvania, No. 4,	(Connellsville field),	87.10
West Virginia, No. 4,	(Upper Freeport bed),	86 26
West Virginia, No. 5,	(Upper Freeport bed),	85 97
West Virginia, No. 3,	(Upper Freeport bed),	85 95
West Virginia, No. 8,	(Kanawha field),	85.86
West Virginia, No. 9,	(Kanawha field),	85 86
West Virginia, No. 1,	(Pittsburg bed),	84.45
Kansas, No. 5,	(Weir-Pittsburg bed),	84.25

West Virginia, No. 2,	(Pittsburg bed),	84 01
Kansas, No 2,	(Weir-Pittsburg bed),	83.81
Alabama, No. 1,	(Warrior field),	83.29
Kentucky, No 1,	(Eastern field),	83.03
Kansas, No. 1,	(Weir-Pittsburg bed),	82 68
Kentucky, No. 4,	(Western field),	82.38
Kansas, No. 4,	(Atchison field),	82.27
Indian Territory, No. 2,	(Hartshorne bed),	82.07
Missouri, No. 4,	(Morgan county),	81 22
Missouri, No. 1,	(Rich Hill field),	80.99
Indian Territory, No 3,	(McAlester bed),	80.17
Alabama, No. 2,	(Warrior field),	80.10
Indian Territory, No. 1,	(Henryetta bed),	79.69
Iowa, No. 1,	(Wapello county),	78.96
Iowa, No. 3,	(Polk county),	78.08
Kentucky, No. 2,	(Western field),	77.85
Illinois, No. 3,	(Marion county),	77.67
Iowa, No 2,	(Marion county),	77.59
Kentucky, No. 3,	(Western field),	77 52
Indiana, No 2,	(Warrick county),	76.89
Indian Territory, No. 4,	(McAlester bed),	76 55
Illinois, No 1,	(Belleville field),	75 59
Wyoming, No 2,	(Cambria field),	75 15
Illinois, No. 6,	(Montgomery county),	74 86
Indiana, No. 1,	(Sullivan county),	74 39
Iowa, No. 4,	(Appanoose county),	72.86
Missouri, No. 2,	(Bevier field),	72.68
Iowa, No 5,	(Lucas county),	72 14
New Mexico, No. 2,	(Black lignite, Gallup field),	71.35
Illinois, No 4,	(Belleville field ,	71.18
New Mexico, No 1,	(Black lignite, Gallup field),	69.74
Montana, No. 1,	(Red Lodge),	69.41
Colorado, No 1,	(Black lignite, Boulder field),	65.71
Texas, No 2,	(Brown lignite, Wood county),	64 05
Texas, No. 1,	(Brown lignite, Houston county),	61 90
Wyoming, No. 1,	(Black lignite, Sheridan field),	61 76
North Dakota, No. 1,	(Brown lignite, Lehigh field),	61.43
North Dakota, No. 2,	(Brown lignite, Williston field),	59 54

In a general way this carbon-classification is satisfactory, the coal showing a fairly regular decrease, in amount of carbon, from Pennsylvania anthracite at the top to brown lignite of North Dakota at the bottom, but the degree of separation between the anthracite and the semi-bituminous coals is not marked, and seemingly not so great as the real difference between those coals would seem to demand. When Table V. is examined in detail, many points seem objectionable; for instance, Arkansas No. 5 is a semi-bituminous coal, which, according to the old scheme, should certainly follow the anthra-

cite in the list, but instead it occurs in fourth place below it. West Virginia No. 11 (Pocahontas) should be in second place below the anthracite, but it occurs in the fifth place. Also, the lignites are not so easily distinguished from some of the bituminous coals, and, in fact, some of the lignites occur above Illinois No. 4, which is a well-marked bituminous coal.

Carbon-Hydrogen Ratio.

The classifications so far given embrace all of the fuel-elements of the coal, or the elements upon which a classification can logically be based.

The percentages of carbon are the most satisfactory of those so far tried, but the carbon is only one of the important fuel-elements of coal. Hydrogen is almost equally valuable, but, as shown in Table IV., this, when taken alone, does not afford a satisfactory basis for classification.

The increased valuation of coal from the grade of brown lignite to anthracite depends upon both carbon and hydrogen—an increase, or at least no diminution, in the amount of the former and a direct loss in the latter. For this reason the ideal classification should take an account of both elements.

Since the percentage of hydrogen decreases as the percentage of carbon increases, the two elements should not be combined by addition or by multiplication, for these processes would tend to equalize the results, and this is undesirable for purposes of classification. Subtraction or division, therefore, must be used to express the desired relation. The latter seems to be the more satisfactory, and therefore Table VI. has been prepared showing these quotients or ratios.

TABLE VI.—*Classification of Coal According to Carbon-Hydrogen Ratio.*

Name of Sample	Name of Coal-Bed or Field	Carbon-Hydrogen Ratio
	Groups A, B and C.	
Pennsylvania, No. 3,	(Anthracite),	26.7
	Group D.	
	Not represented.	
	Group E.	
Arkansas, No. 5,	(Spadra bed),	20.7

Group F.

West Virginia, No. 11,	(Pocahontas bed),	19.6
Arkansas, No. 2,	(Huntington bed),	19.3
West Virginia, No. 12,	(Pocahontas field),	19.2
Arkansas, No. 1,	(Huntington bed),	18.9
Arkansas, No. 3,	(Huntington bed),	18.8
West Virginia, No. 7,	(New River field),	18.8
West Virginia, No. 10,	(Pocahontas field),	18.7
West Virginia, No. 6,	(New River field),	17.8

Group G.

West Virginia, No. 4,	(Upper Freeport bed),	16.1
West Virginia, No. 5,	(Upper Freeport bed),	15.9
Pennsylvania, No. 4,	(Connellsville field),	15.7
West Virginia, No. 9,	(Kanawha field),	15.7
West Virginia, No. 3,	(Upper Freeport bed),	15.5
West Virginia, No. 8,	(Kanawha field),	15.3
West Virginia, No. 1,	(Pittsburg bed),	14.7
Kentucky, No. 1,	(Eastern field),	14.6
Kentucky, No. 4,	(Western field),	14.6
Alabama, No. 1,	(Warrior field),	14.5
Alabama, No. 2,	(Warrior field),	14.5
Kansas, No. 5,	(Weir-Pittsburg bed),	14.5
West Virginia, No. 2,	(Pittsburg bed),	14.4

Group H

Indian Territory, No 2,	(Hartshorne bed),	14.3
Indian Territory, No. 3,	(McAlester bed),	14.1
Kansas, No 1,	(Weir-Pittsburg bed),	13.9
Kansas, No. 2,	(Weir-Pittsburg bed),	13.8
Illinois, No. 3,	(Marion county),	13.7
Indian Territory, No. 1,	(Henryetta bed),	13.6
Iowa, No 1,	(Wapello county),	13.4
Indian Territory, No. 4,	(McAlester bed),	13.1
Kansas, No 4,	(Atchison field),	12.9
Missouri, No. 1,	(Rich Hill field),	12.9
Kentucky, No. 2,	(Western field),	12.7
Kentucky, No. 3,	(Western field),	12.6
Missouri, No. 4,	(Morgan county),	12.6

Group I.

Iowa, No. 2,	(Marion county),	12.4
Illinois, No. 6,	(Montgomery county),	12.3
Indiana, No 2,	(Warrick county),	12.3
Iowa, No 3,	(Polk county),	12.3
Illinois, No. 1,	(Belleville field),	12.2
Wyoming, No. 2,	(Cambria field),	12.2
Indiana, No. 1,	(Sullivan county),	11.9
Illinois, No 4,	(Belleville field),	11.6
Iowa, No. 4,	(Appanoose county),	11.5
Montana, No. 1,	(Red Lodge),	11.5
Missouri, No. 2,	(Bevier field),	11.3
Iowa, No. 5,	(Lucas county),	11.2

	Group J.	
New Mexico, No. 1,	(Black lignite, Gallup field),	11.2
New Mexico, No. 2,	(Black lignite, Gallup field),	11.2
Texas, No. 2,	(Brown lignite, Wood county),	10.9
Colorado, No. 1,	(Black lignite, Boulder field),	10.6
North Dakota, No. 1,	(Brown lignite, Lehigh field),	10.1
North Dakota, No. 2,	(Brown lignite, Williston field),	9.8
Wyoming, No. 1,	(Black lignite, Sheridan field),	9.6
Texas, No 1,	(Brown lignite, Houston county),	9.4
	Group K.	
Peat,		9.1

In considering schemes of classification, it must be remembered that our present knowledge of the chemical composition of coal is very imperfect, and any scheme that may be put forward depends to a certain extent on unknown or little-understood factors. For this reason Table VI. must be regarded as provisional.

The points of greatest weakness are our ignorance of the character of the volatile combustible matter and also of what is usually called moisture. A few experiments made at St. Louis seem to indicate that something more than moisture frequently passes off from coal at ordinary temperatures, and hence the moisture, as shown in the analyses, possibly includes some of the lighter hydrogen compounds. Also, it is doubtful whether we should regard water as a non-fuel element, for in many cases, it is dissociated and its hydrogen becomes available for fuel-purposes.

Many of these questions are to be investigated at St. Louis during the coming summer, and it is quite possible that the results there obtained may change slightly the figures given in the accompanying tables, but it is thought that the result will be a modification only, and not a direct conflict with the results herein given.

So far as I am acquainted with the character and fuel-value of the coals tested, the classification given in Table VI. seems to be almost ideal. It is not only correct in a general way, but in detail it seems to fit almost every case. True, the separation between bituminous coal and lignite is not sharp and distinct, but it is highly probable that there is no sharp distinction between these two classes, and that the facts are best represented by a merging of the values, as shown in the table.

I, therefore, propose provisionally, that the carbon-hydrogen ratios be taken as the basis of a new scientific classification of coals, applicable to all varieties, from the highest class of anthracite to the lowest grade of brown lignite and peat.

Possible Exceptions.

The evidence upon which the carbon-hydrogen classification is based is not sufficient for its final acceptance. It is quite possible that it may fail in some cases, but it is simply put forward at this time in a tentative way to invite discussion and investigation. The coals so far examined are of diverse characters, and include most of the various kinds known in this country, except cannel coal. Owing to the low percentage of fixed carbon and the relatively high percentage of volatile combustible matter in cannel coal, the ratio between the total carbon and the hydrogen may possibly be so low, that, according to this scheme, it will fall below its normal position. This matter, however, being purely theoretical, can be decided only by actual trial when the ultimate analysis of a typical cannel coal is available.

Resumé.

The results obtained in this investigation may be summarized as follows: (1) Fuel-ratios, or any of the components of coal, determined by a proximate analysis, are worthless for purposes of classification except for highly carbonized fuel as anthracite, semi-anthracite and semi-bituminous coal. (2) Calorific values are equally unsuited, but in this case the failure is particularly well-marked in the upper part of the list of coals. (3) Of the elements shown by an ultimate analysis, carbon is the only one at all satisfactory, and even this fails in detail. (4) Carbon-hydrogen ratios form a satisfactory basis for classification,—a scheme which applies perfectly to all samples of fuel tested at St. Louis during the past year which included representative samples of all kinds of coal, except cannel and some classes of anthracite and semi-anthracite. (5) Twelve groups of coals and allied compounds are suggested as follows:

TABLE VII.—*Proposed Groups of Coal and Allied Substances.*

		Carbon-Hydrogen Ratio.
Group A (graphite),		∞ to (?).
Group B,	(anthracite),	(?) to 30 (?)
Group C,	(anthracite),	30 (?) to 26 (?)
Group D (semi-anthracite),		26 (?) to 23 (?)
Group E (semi-bituminous),		23 (?) to 20
Group F,	(bituminous),	20 to 17
Group G,	(bituminous),	17 to 14.4
Group H,	(bituminous),	14.4 to 12.5
Group I,	(bituminous),	12.5 to 11 2
Group J (lignite),		11.2 to 9.3
Group K (peat),		9.3 to (?)
Group L (wood, cellulose),		7.2

Groups A, B, C, D and E.—As little work on anthracite coal was done at the testing-plant, and as all of the analyses made by the Second Geological Survey of Pennsylvania were proximate analyses, there is little material available for determining the limits of these groups; hence the figures given must be regarded as provisional only, and subject to change when more ultimate analyses have been made.

Groups F, G H, and I.—These groups embrace what generally are considered as bituminous coals. Group F includes Pocahontas coal, the high-grade Arkansas coals west of the Spadra district, and New River coals. Group G includes Upper Freeport and Pittsburg coals of northern West Virginia, Kanawha Valley coals, high-grade Kentucky coals, and Alabama coals. Group H includes Indian Territory coals, Kansas coals, high-grade Illinois, Iowa and Missouri coals, and second-grade Kentucky coals. Group I includes the great majority of Iowa, Illinois, Missouri and Indiana coals, and some bituminous coals from Wyoming and Montana.

Groups J, K and L.—Group J includes all of the lignites, both black and brown, that were tested. Group K, limited to peat, is based entirely upon one analysis obtained from outside sources. Group L is wood (cellulose), the lowest class in the series.

The Commercial Value of Coal-Mine Sampling.*

BY MARIUS R. CAMPBELL, WASHINGTON, D. C.

(Washington Meeting, May, 1905.)

Introduction.

Does mine-sampling show the commercial value of a coal, and if so, how should it be done? This question is often asked, but seldom answered. During the past summer, while engaged in securing coal for the Government coal-testing plant at St. Louis, I had an excellent opportunity to obtain information on this subject, and the results seem to furnish an answer to the question propounded above.

Sampling for the U. S. Geological Survey Coal-Testing Plant.

In organizing the work of the testing-plant, it was decided that coal, in car-load lots only, would be accepted for testing; also that this coal should be loaded under the immediate supervision of a representative of the plant, so as to be certain that the car-load sample would be representative. As an additional check on the work, two mine-samples were to be collected from each mine visited, and these samples, as well as the sample from the car when it was received at the testing-plant, were to be carefully analyzed at the chemical laboratory established in connection with the plant and operated under the direction of Prof. N. W. Lord of the Ohio State University, Columbus, Ohio.

Mine-Sampling.—Mine-samples were collected with great care by me and my assistants, Messrs. J. Shober Burrows, John W. Groves and Frank W. De Wolf.

The dominant idea in the regulations adopted for mine-sampling was, that it should be done in such a manner that the sample would have the same composition as the commercial output of the mine.

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When samples were to be secured from a certain place, the mine was examined to see the coal before it was mined,—the benches, partings, roof and floor, and any peculiarity that might be present. The methods of mining were observed, and also the efforts that were made in the mine and at the tipple to free the coal from its accompanying impurities.

Two places for sampling were then selected in widely separated localities in the mine. The floor was carefully cleaned and an oilcloth blanket spread to catch the coal and prevent it from becoming mixed with fragments of shale or dirt, also to keep the sample from collecting an undue amount of moisture in places where the floor was wet.

A cut, about 3 in. wide and 1 in. deep, was made across the face of the coal from roof to floor, including thin and irregular shale, clay or sulphur partings, such as the miners fail to separate from the coal, and excluding thick partings or dirty coal that usually are thrown out by the miners. The object was to get as near a good grade of merchantable coal as possible with the methods of mining and handling in vogue at the mine.

The sample so obtained weighed 25 or 30 lb., and was usually placed in a bag and taken to the surface, where it was pulverized and quartered-down. Sometimes it was pulverized at once to the desired degree of fineness (about $\frac{1}{2}$ in.), but more frequently it was pulverized to $\frac{3}{4}$ in. and divided into quarters. Then opposite quarters were taken and pulverized again, until the coal was about $\frac{1}{2}$ in. in size. It was then quartered again until the resulting sample contained about 1 quart of fine coal. This was placed in a galvanized-iron sample-can provided with a screw-top, which was screwed down tightly and the joint bound with tire-tape, making the can air-tight. These cans were mailed direct to the chemical laboratory, where the coal was immediately transferred to glass jars, in which it was hermetically sealed.

After securing the mine-samples, the inspector went to the surface and observed the loading of a car of coal for testing-purposes. He permitted only such hand-picking as was commonly done in preparing coal for the market, and in every way possible provided for a representative sample. The grade of coal selected usually depended upon local conditions, but the

aim was to take only such coal as was considered typical and merchantable.

In the case of soft coal or lignite, liable to disintegrate under the influence of the weather, box-cars were used wherever practicable; but the great bulk of the bituminous coal was shipped in ordinary open coal-cars.

Most of the coal was shipped during August, September, October and November,—a period in which the weather was unusually dry in the vicinity of St. Louis. For this reason it seems probable that any change in the amount of moisture in the coal in transit was due to ordinary atmospheric conditions which would probably have a similar effect on the coal shipped in either open cars or box-cars.

Car-Sampling.—When the car of coal arrived at the testing-plant it was unloaded; and the coal was passed through rolls having an aperture of 1.5 in., reducing it to a uniform size. As the coal was being elevated by bucket-conveyors, a man with a small shovel took samples from the conveyor at regular intervals. By this method a sample of 200 or 300 lb. was obtained from each car, and taken direct to the chemical laboratory for analysis.

The original intention was to unload the car at once into a storage-bin, but owing to a scarcity of bins this was not always practicable, and, in a majority of cases, the coal was unloaded a few tons at a time, only sufficient for a single test. A sample was taken of the coal used for each test, however, and the moisture, sulphur and ash, given in Tables I., II. and III., were determined by taking the average of the various analyses made.

At the laboratory both the mine- and car-samples were pulverized, and quartered-down by machinery until a convenient quantity was obtained. Part of this was taken for analysis and the remainder was sealed in a glass jar for future reference.

The sample to be analyzed was first air-dried until it reached an almost constant weight, and the loss of moisture by this process was determined. The sample was then analyzed, and its composition was recalculated on the basis of the coal as received.

TABLE I.—*Impurities in Mine- and Car-Samples of Coal.*

Name of Sample.	Average Percentages of Impurities.			Excess in Car-Sample			Excess in Mine-Sample.		
	Moisture.	Sulphur.	Ash.	Moisture.	Sulphur.	Ash	Moisture.	Sulphur	Ash.
	Per Cent	Per Cent	Per Cent.	Per Cent.	Per Cent	Per Cent.	Per Cent.	Per Cent	Per Cent.
Alabama 1.									
2 mine-samples....	1.28	0.71	13.22	....	....	....	....	......	......
3 car-samples......	2 52	0.75	13.44	1.24	0.04	0 22	....	......	......
Alabama 2.									
2 mine-samples....	2.33	1.09	10.08	....	....	....	....	......	...
4 car samples......	3.93	1.12	12.13	1 60	0.03	2.05	....	......	......
Arkansas 1.									
2 mine-samples....	0 88	1.12	7.23	....	....	....	....	......	......
3 car-samples	2.51	1.19	12.89	1.63	0.07	5.66	....	......	......
Arkansas 2.									
2 mine-samples....	0.86	2.31	8.03	....	....	....	....	......	......
3 car-samples	1.87	1.80	9.39	1.01	....	1.36	....	0.51	......
Arkansas 3.									
2 mine-samples. .	1.61	1.44	10.28	....	....	....	....	......	......
2 car-samples.. ...	2.08	1.28	10.44	0 47	....	0.16	....	0.16	......
Arkansas 5.									
2 mine-samples....	1.59	1.73	7.20	....	....	....	....	......	......
2 car-samples.. ...	2.29	2.19	11.82	0.70	0.46	4 62	....	......	......
Colorado 1.									
2 mine-samples....	20 93	0.49	3.54	....	....	....	....	......	......
3 car-samples......	19.57	0.52	5.74	....	0.03	2.20	1.36	......	......
Illinois 1.									
2 mine-samples....	10.61	4.13	10.19	....	....	....	....	......	......
3 car-samples.. ..	9.97	4 21	14.78	....	0.08	4.59	0.64	......	......
Illinois 3.									
2 mine samples...	7.42	1.51	7.34	....	....	....	....	......	......
4 car-samples......	8.22	1.59	10.79	0.80	0 08	3.45	....	......	......
Illinois 4.									
2 mine-samples ...	14.75	1.17	8.11	....	....	....	....	......	......
4 car-samples	12.94	1.34	10.77	....	0.17	2.66	1.81	......	......
Illinois 6.									
2 mine-samples....	14.41	3.70	9.39	....	....	....	....	......	......
2 car-samples . .	13.81	3.74	14.08	....	0.04	4.69	0.60	......	......
Indiana 1									
2 mine-samples....	12.37	1.41	9.39	....	....	....	....	......	......
2 car-samples.. . .	11.45	2.55	11 74	....	1.14	2.35	0 92	......	......
Indiana 2.									
2 mine-samples....	9.80	3.97	8 94	....	....	....	....	......	......
3 car-samples......	9.15	4.29	11.73	....	0.32	2.79	0.65	......	......
Indian Territory 1.									
2 mine-samples....	7.82	1.49	7.15	....	....	....	....	......	......
4 car-samples.... .	7.49	1.62	11.12	....	0.13	3.97	0.33	......	......
Indian Territory 2.									
2 mine-samples....	1.38	1.48	7.02	....	....	....	....	......	......
3 car-samples......	3.99	1.46	10.25	2.61	....	3.23	....	0 02	......
Indian Territory 3.									
2 mine-samples....	2.95	3.39	9.34	....	....	....	....	......	......
3 car-samples......	4.52	3.57	10.41	1.57	0.18	1.07	....	......	......
Indian Territory 4.									
2 mine-samples....	5.89	3.72	10.72	....	....	....	....	......	......
2 car-samples......	6.24	3.91	13.10	0.35	0.19	2.38	....	......	......
Iowa 1.									
2 mine-samples....	11.71	4.85	11.42	....	....	....	....	......	......
2 car-samples	8.46	5.71	17.17	....	0.86	5.75	3.25	......	......

TABLE I.—*Continued.*

Name of Sample	Average Percentages of Impurities.			Excess in Car-Sample.			Excess in Mine-Sample		
	Mois-ture.	Sul-phur.	Ash.	Mois-ture	Sul-phur.	Ash.	Mois-ture.	Sul-phur.	Ash.
	Per Cent	Per Cent.	Per Cent.	Per Cent	Per Cent	Per Cent.	Per Cent.	Per Cent	Per Cent.
Iowa 2.									
2 mine-samples....	15.57	5.14	10.41	....	....	....	....	....	.....
2 car-samples	14.54	4.69	15 63	....	....	5.22	1.03	0 45	..
Iowa 3.									
2 mine-samples....	15.16	6.32	11.68	....	....	....	....	. ....	.....
2 car-samples	13.16	6.11	14.83	....	....	3.15	2.00	0.21	.....
Iowa 4.									
2 mine-samples....	16.63	4.38	9.07	.. ..	..... .	....	....	.....	.....
2 car-samples	13 76	4.65	13.05	....	0.27	3.98	2.87	.....	.....
Iowa 5.									
2 mine-samples....	18 64	2.74	7.44	.... .	..... .	....	....	.....	.....
2 car-samples......	15.70	3.14	13.01	....	0.40	5.57	2.94	.....	.....
Kansas 1.									
2 mine-samples....	3.20	3 53	8.73	....	. ...	.. . . .	....	....	.....
4 car-samples .	5.95	4 38	13.15	2.75	0 85	4.42	..... .	... ...	.....
Kansas 2.									
2 mine-samples...	2.40	5.75	11.19	....	....	....	....	....	.....
2 car-samples......	4.07	5.93	18.97	1.67	0.18	7.78	....	... ...	.....
Kansas 3.									
2 mine-samples....	2.27	4.87	12.51	....	.. ..	....	....	. ....	.....
4 car-samples ..	2.13	5.37	13.80	....	0.50	1.29	0.14	......	.....
Kansas 5.									
2 mine-samples.. .	5.45	4 09	10.72	....	... .	.. ..	....	......	.....
2 car-samples . .	4.20	4 08	11.22	..... .	....	0 50	1.25	0.01	.....
Kentucky 1.									
2 mine-samples ..	2.86	0.86	3.16	....	. ...	....	....	......	.....
3 car-samples ..	2.90	1.21	4.73	0.04	0.35	1.57	. ...	.....	.....
Kentucky 2									
2 mine-samples....	8.14	3.86	8.66	....	....	....	....	....	.....
2 car-samples	7 83	3.49	8.85	....	....	0.19	0.31	0.37	.....
Kentucky 3									
2 mine-samples....	8 54	3.50	8.67	....	....	. . ..	....	....	.....
3 car-samples....	7.71	3.76	9.66	....	0.26	0 99	0.83	......	.....
Kentucky 4.									
2 mine-samples ..	4.68	3.27	7.20	....	....	.. ..	....	....	.....
2 car-samples ...	5.58	4.13	13.45	0.90	0.86	6.25	....	. ....	.....
Missouri 1.									
2 mine-samples....	4.86	5.34	14.34	....	....	....	....	... .	.....
4 car-samples .. .	7.80	4.81	18.28	2.94	. ...	3.94	.. ....	0 53	...
Missouri 2.									
2 mine-samples....	13.82	3.81	9.22	....	....	....	..... .	. ....	.....
4 car-samples......	11.94	4.81	16.32	....	1.00	7.10	1.88	. ....	.....
Missouri 4.									
2 mine-samples....	11.95	5.03	6.53	.... ..	....	....	....	. . .	.....
3 car-samples......	12.32	5.08	5.22	0.37	0.05	....	....	. ..	1.31
New Mexico 1.									
2 mine-samples....	11 36	0.53	3.63	....	.. ..	....	.. ..	......	....
2 car-samples ...	12.09	0.59	7.83	0 73	0.06	4 20	....	......	.....
Texas 1.									
2 mine-samples....	33.04	0.56	10.79	....	....	.. ..	....	....	.....
2 car-samples......	34.10	0.71	10.78	1.06	0.15	....	....	......	0.01
Texas 2.									
2 mine-samples....	30.10	0.53	8 21	....	... ...	....	....	......	......
1 car-sample.......	33.71	0.53	7.28	3.61	.. ....	....	....	. ....	0.93

TABLE I.—*Concluded.*

Name of Sample.	Average Percentages of Impurities			Excess in Car-Sample.			Excess in Mine-Sample.		
	Moisture.	Sulphur.	Ash.	Moisture	Sulphur	Ash	Moisture	Sulphur	Ash.
	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent.	Per Cent	Per Cent.	Per Cent	Per Cent.
West Virginia 1.									
2 mine-samples	1 37	1.45	6.54						
4 car-samples	1.80	0.91	6.57	0.43		0.03		0.54	
West Virginia 2.									
2 mine-samples	1.92	3.97	8.59						
3 car-samples	1.90	3.19	8.68			0 09	0.02	0.78	
West Virginia 3.									
2 mine-samples	2.55	0.77	8.25						
3 car-samples	2.36	1.14	10.34		0.37	2.09	0.19		
West Virginia 4.									
2 mine-samples	2.26	1.05	8.16						
4 car-samples	2.18	0.88	9.42			1.26	0.08	0.17	
West Virginia 5.									
2 mine-samples	2.95	1.06	10.36						
3 car-samples	2.00	0.96	10.37			0.01	0.95	0.10	
West Virginia 6.									
2 mine-samples	2.19	0 74	4.71						
5 car-samples	1.92	0.68	5.22			0.51	0.27	0 06	
West Virginia 7.									
2 mine-samples	2.30	0.99	3.85						
3 car-samples	3.49	1.35	6.26	1.19	0 36	2.41			
West Virginia 8.									
2 mine-samples	1.87	0.76	5.81						
3 car-samples	4.41	0.84	7.08	2 54	0.08	1.27			
West Virginia 9									
2 mine-samples	1.87	0.79	3.35						
4 car-samples	3.49	0.85	6.59	1.62	0.06	3.24			
West Virginia 10									
2 mine-samples	2 78	0 52	3 37						
3 car-samples	1.70	0.59	5.38		0.07	2 01	1.08		
West Virginia 11.									
2 mine-samples	2.63	0.47	4.91						
3 car-samples	4 09	0.48	10.52	1.46	0.01	5.61			
West Virginia 12.									
2 mine-samples	2.70	0.62	4.14						
4 car-samples	1 56	0.80	6.08		0.18	1.94	1.14		
Wyoming 1.									
2 mine-samples	21.72	0.56	4.14						
2 car-samples	22.22	0 61	5.26	0.50	0.05	1.12			
Wyoming 2.									
2 mine-samples	8.91	4.63	21.43						
2 car-samples	10 27	3.89	19.74	1.36				0.74	1 69
Totals				35.15	9.93	130 94	26.54	4.65	3.94
Total samples				26	35	46	24	14	4
Averages				1.35	0 28	2.85	1.11	0.33	0.98
Total in mine-samples			418 36						
Total in car-samples			545 36						

Analytical Results.[1]

During the season, 50 separate mines in 14 States were visited, and mine- and car-samples obtained. Table I. shows the analyses of these samples so far as moisture, sulphur and ash are concerned. The analyses of the two mine-samples have been averaged and the percentages of moisture, sulphur and ash thus obtained are regarded as representing the impurities obtained in mine-sampling. The analyses of the various car-samples have been averaged, and the result is taken as the amount of moisture, sulphur and ash in the commercial product of the mine.

Conclusions.

Moisture.—In Table I. the gains and losses in the amount of moisture in the coal are about equally balanced. In the entire lot of 50 samples, 26 show a gain of moisture in the average of the car-analyses, and the average amount of gain expressed in percentage is 1 35. In 24 cases there is an excess of moisture in the mine-sample over the car-sample, and the average percentage of excess is 1.11. These figures are so nearly the same, that, considered as a whole, there was no perceptible gain or loss of moisture in transit or in the car-samples as compared with the mine-samples.

In analyzing these figures more closely, however, it is seen that four of the lignites show a gain in moisture and one shows a loss. The lignites showing gain are New Mexico No. 1, Texas No. 1, Texas No. 2, and Wyoming No. 1. These were shipped in box-cars; but, despite this fact, they show a perceptible gain in moisture, while Colorado No. 1, shipped in an open car, shows a loss of moisture. The average gain in the lignites taken as a whole is 0.91 per cent.

The greatest loss of moisture seemed to have occurred in the bituminous coals with an originally high moisture-content. As shown in Table II., 19 samples of this kind of coal have a moisture-content in the mine-samples of 5 per cent. or more.

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[1] For a detailed description of the coal-samples see Preliminary Report on the Operations of the Coal-Testing Plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904. *Bulletin No.* 261, *U. S. Geological Survey* (1904). A detailed report of this work is now in press.

TABLE II.—*Coals Containing More than* 5 *Per Cent. of Moisture in the Average Mine-Samples (Exclusive of Lignites).*

Name of Sample	Average Moisture in Mine-Samples	Average Moisture in Car-Samples.	Excess in Mine-Samples	Excess in Car-Samples.
	Per Cent	Per Cent.	Per Cent.	Per Cent.
Illinois No. 1	10.61	9.97	0.64	....
Illinois No 3	7.42	8.22	....	0.80
Illinois No. 4	14.75	12 94	1.81	....
Illinois No. 6	14.41	13 81	0 60	....
Indiana No. 1	12.37	11.45	0 92	....
Indiana No. 2	9.80	9.15	0.65	....
Indian Territory No. 1	7.82	7.49	0.33	....
Indian Territory No. 4	5.89	6.24	....	0.35
Iowa No. 1	11.71	8.46	3.25	....
Iowa No. 2	15.57	14.54	1.03	....
Iowa No. 3	15.16	13.16	2.00	....
Iowa No. 4	16.63	13.76	2.87	....
Iowa No. 5	18.64	15 70	2.94	....
Kansas No. 5	5.45	4.20	1.25	....
Kentucky No 2	8.14	7.83	0 31	....
Kentucky No. 3	8.54	7.71	0.83	....
Missouri No. 2	13.82	11.94	1.88	....
Missouri No. 4	11.95	12.32	....	0.37
Wyoming No. 2	8.91	10.27	....	1.36
Totals	217.59	199.16	21.31	2.88

The average excess of moisture in the mine-samples is 21.31 ÷ 15 = 1.42 per cent.

The average excess of moisture in the car-samples is 2.88 ÷ 4 = 0.72 per cent.

The coefficient of decrease from mine-sample is 199.16 — 217.59 = 0.915. Therefore in sampling coals which run 5 per cent. or more in the mine-sample, the probable amount of moisture in the commercial-sample can be obtained by multiplying by the coefficient 0.915.

As shown in Table III., 26 samples of bituminous coal contain less than 5 per cent. of moisture in the mine-samples.

The average excess of moisture in the car-samples is 26.37 ÷ 18 = 1.47 per cent.

The average excess of moisture in the mine-samples is 3.87 ÷ 8 = 0.48 per cent.

The coefficient of excess, in car-samples over the mine-samples, is 83.04 — 60.54 = 1.37. Therefore, in sampling coals which run less than 5 per cent. of moisture in the mine-sample, the moisture in the commercial-sample can be obtained with considerable probability by multiplying by the coefficient 1.37.

TABLE III.—*Coals Containing Less than 5 Per Cent. of Moisture in the Average Mine-Samples.*

Name of Sample	Average Moisture in Mine-Samples.	Average Moisture in Car-Samples.	Excess in Mine-Samples	Excess in Car-Samples.
	Per Cent.	Per Cent.	Per Cent	Per Cent.
Alabama No. 1.	1.28	2.52	....	1.24
Alabama No. 2.	2.33	3.93	....	1.60
Arkansas No. 1.	0.88	2.51	....	1.63
Arkansas No. 2.	0.86	1.87	....	1.01
Arkansas No. 3.	1.61	2.08	....	0.47
Arkansas No. 5.	1 59	2.29	....	0.70
Indian Territory No. 2.	1.38	3.99	....	2.61
Indian Territory No. 3.	2.95	4 52	....	1.57
Kansas No 1.	3 20	5.95	....	2.75
Kansas No. 2.	2.40	4 07	....	1.67
Kansas No. 3	2.27	2.13	0 14	....
Kentucky No. 1.	2.86	2.90	....	0.04
Kentucky No. 4.	4 68	5.58	....	0.90
Missouri No 1	4.86	7.80	....	2.94
West Virginia No. 1	1.37	1 80	....	0.43
West Virginia No. 2.	1.92	1.90	0.02	....
West Virginia No. 3.	2.55	2.36	0.19	....
West Virginia No. 4	2.26	2.18	0.08	....
West Virginia No. 5	2.95	2 00	0.95	....
West Virginia No. 6.	2.19	1.92	0.27	....
West Virginia No. 7	2.30	3.49	....	1.19
West Virginia No. 8.	1 87	4.41	....	2.54
West Virginia No. 9	1.87	3 49	....	1 62
West Virginia No. 10.	2.78	1.70	1.08	....
West Virginia No. 11	2 63	4 09	....	1.46
West Virginia No 12	2.70	1.56	1.14	....
Totals.	60 54	83.04	3.87	26.37

Although the figures given in Tables I., II. and III. show, in a general way, that the amount of moisture in car-load lots of coal is little different from that contained in mine-samples, there are slight variations in certain classes of coals, as noted above, which may be summarized as follows:

1. Lignites and lignitic coals are apt to show a greater percentage of moisture in the car-sample than in the mine-sample, but the percentage of gain is small.

2. Bituminous coals having a high moisture-content (more than 5 per cent.) are apt to show less moisture in the car-sample than in the mine-sample, and the amount of loss is about 1.5 per cent.

3. Bituminous and semi-bituminous coals with a small moisture-content (less than 5 per cent.) generally show a gain in moisture in the car-sample, and the amount of gain is about 1.5 per cent.

Sulphur.—The variation in the percentage of sulphur in the mine- and car-samples is not great. Thirty-five samples show more sulphur in the car- than in the mine-sample, and 14 cases show less. The average amount of gain in 35 samples is 0.28 per cent., and the average loss in 14 samples is 0.33 per cent.

The general average of the sulphur in all analyses shows an increase in the car-sample above that contained in the mine-sample. This increase is, therefore, regarded as general, and due to more rigid exclusion of impurities in selecting the mine-sample than the miners exercised in loading commercial coal. The coefficient of increase in the 50 samples at hand is 1.04; therefore, it is probable that in mine-sampling, for the purpose of determining the amount of sulphur in the commercial output of the mine, it is necessary to multiply the amount in the mine-sample by this coefficient, 1.04. When the percentage of sulphur is small, the amount to be added is insignificant and may be disregarded; but when the percentage is large, the increase is correspondingly great, and should be taken into consideration.

Ash.—The greatest and most constant variation in the two classes of samples is in the ash, which was found to be so different in the car-sample from what it was in the mine-sample, that allowance should be made for the difference in all careful sampling for commercial purposes.

Of the 50 analyses compared, 46 show a greater amount and 4 show a smaller amount of ash in the car-sample than in the mine-sample. This is so nearly uniform that it may be regarded as a general rule. The total ash in the mine-samples, as shown in Table I., is 418.36 per cent. The total ash in the car-samples is 545.36 per cent. $545.36 \div 418.36 = 1.3$; if, therefore, the amount of ash in any given mine-sample be multiplied by this coefficient, 1.3, the result will approximate the amount of ash that may be expected in the commercial output of the mine.

As shown by the footings of Table I., 46 samples give a gain of 130.94 per cent., and 4 samples give a loss of 3.94 per cent. The net result is, therefore, a gain of $130.94 - 3.94 = 127$ per cent. Since this is based on the analyses of 50 samples, the average gain in each case is $127 \div 50 = 2.54$ per cent.

Since many of the cars were loaded with run-of-mine coal, it is possible that this grade of coal contains a greater excess of ash than the cars loaded with lump coal; and, therefore, it is responsible for the great increase in the percentage of ash. If a separation is made on this basis, it is found that, of the 50 samples, 29 consist of run-of-mine coal. The 29 samples of run-of-mine coal show an excess of only 2.31 per cent., or 0.23 per cent. less than the average. Not only is the average excess of run-of-mine coal less than the general average for the whole, but also the 29 samples of run-of-mine coal include all of the cases (4 in number), in which the ash in the mine-sample exceeds the ash in the car-samples. From these figures it is obvious that the great excess of ash in the car-samples was not caused by run-of-mine coal.

As might be expected, the personal element enters into the question of sampling to a considerable extent. In the present case, A collected 23 samples, and the average amount of ash in the car-samples collected by him exceeds the average amount of ash in his mine-samples by 2.4 per cent. B collected 16 samples, and the excess in his case amounts to 3.49 per cent. C collected 8 samples and the excess is 1.66 per cent. D collected only 3 samples; but it is manifestly unsafe to generalize from so small an amount. With regard to the samples collected by A, B and C, however, the results are apparently reliable, and they show that B was probably much more careful than the others in not excluding impurities from his mine-samples, and, consequently, the excess of ash in his car-samples is large. A attained about the happy medium and his samples show an excess (2.4 per cent.) only a little below the average excess (2.54 per cent.) for the whole. C, on the other hand, has a much smaller excess, and in his mine-sampling much less of the impurities were included than in the samples of A and B, but even in this case there was an appreciable excess in the car-sample.

As already stated, the rules and regulations adopted for mine-sampling in this work, aimed to secure samples which would correspond with the commercial product of the mine. The results just given show that this was not attained, and, furthermore, they show that a strong personal element necessarily comes in when certain things are left to the judgment of the

sampler. Such a system may be fairly satisfactory where one man does all the sampling, but this is seldom possible. In the light of the results obtained in this work, it seems to me that some arbitrary system that will eliminate the personal equation entirely is much better for general work, and, therefore, I recommend the following method of mine-sampling:

Proposed Method of Mine-Sampling.

1. Select a fresh face of coal, and clean it of all powder-stains and other impurities.

2. Cut a channel perpendicularly across the face of the coal from roof to floor (except as noted in section 3), of such a size as to yield at least 5 lb. of coal per foot of thickness of coal-bed; that is, 5 lb. for a bed 1 ft. thick, 10 lb. for a bed 2 ft. thick, 20 lb. for a bed 4 ft. thick, etc.

3. All material encountered in such a cut should be included in the sample, except partings or binders of more than 0.25 in. in thickness, and except all lenses or concretions of sulphur or other impurities which are greater than 2 in. in maximum diameter and 0.5 in. in thickness.

4. The sample may be sent to the laboratory as it is cut, or it may at once be quartered down to about the size of a quart. If it is quartered-down, it should be pulverized to about $\frac{3}{8}$-in., and, after thorough mixing, it should be divided into quarters and opposite quarters rejected. The operation of mixing and quartering should be repeated until the desired size of sample is obtained. The operation of pulverizing and quartering should be done as rapidly as possible, so as to prevent a serious change in the moisture-content, and then the sample should be sealed in either a glass jar or screw-top can, bound with tire-tape, and sent to the laboratory for analysis.

5. The analysis of such a sample will show the grade of coal that may be obtained by careful mining and picking. In the majority of cases the sulphur and ash in the commercial output of the mine will exceed the amount obtained from the sample, but this latter can be approximated by multiplying by certain coefficients. The coefficients determined in the work of the Geological Survey coal-testing plant last year are not strictly applicable, since the sampling was not done under this system; but they are approximately the same and can be used until

more accurate coefficients are determined. When sufficient data is at hand, it seems possible that exact coefficients may be determined for certain fields; that is, a coefficient for the Appalachian field, another coefficient for the Eastern Interior field, etc., and, finally, coefficients may be determined for local subdivisions of the larger fields, or for certain beds of coal within those fields.

6. All descriptions of samples should state definitely how the samples were obtained, so that the reader may judge for himself the value of the results obtained; and when analyses are recalculated, the coefficients of increase or decrease should be given, together with the authority for using this coefficient, or the data upon which it was determined.

A Machine for Drawing Coke from Bee-Hive Ovens.

BY GEORGE T WICKES, COVINGTON, VIRGINIA.

(Washington Meeting, May, 1905.)

SEVERAL years ago, Mr. Robert A. Cook described and illustrated in our *Transactions*[1] a mechanical coke-drawer, patented in 1891 by Mr. Thomas Smith of the Thorncliff Iron Works, Sheffield, England, and first introduced in the United States in 1896, at the coking-plant of the Latrobe Coal Co., Latrobe, Pa. This machine has not received any very extended application in this country, although it was successfully used in two places for a number of years. The present paper describes a new and simpler machine, containing few wearing-parts, and capable of withstanding continued rough usage.

Anything which tends to prolong the general use of bee-hive ovens will be welcome to those who are interested in cheapening the cost of producing coke in such ovens, especially if it provides satisfactory mechanical means, replacing the hard labor involved in drawing coke by hand with the old-fashioned "duck bill." The difficulty of finding efficient coke-drawers, especially during the summer season, and in the South, is notorious. Yet, notwithstanding the great improvements that have

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[1] *Trans.*, xxvi., 347–350 (1896).

been made in retort coke-ovens, new bee-hive ovens are continually constructed; and a machine which will successfully compete with hand-drawing, and, at the same time, add to the efficiency of the bee-hive oven, seems to deserve notice.

The machine here described was put in operation in October, 1904, at the Frick Coal and Coke Co.'s plant at Uniontown, Pa., known as Continental No. 1, and is reported to have met successfully all the tests to which it has been subjected. This trial has demonstrated that one of these machines, equipped with an electric motor, and operated by one man with an assistant, besides two men to "water down" the ovens in advance of the machine, and one man to clean out what little coke may remain in the oven after the machine has finished its work, will, with the aid of the accompanying conveyor, draw more than 30 ovens per day of 10 hr. and load the coke on cars for shipment.

Possibly not every one will agree with me in advocating deep charges as against shallow ones; but to those who believe that the loss in fixed carbon is smaller in the deep charge, the advantage of the machine over hand-drawing must be apparent, since no charge is too deep to prevent the machine from drawing it with ease. Therefore, the economical charge for a given oven may be fixed and determined by the operator, without regard to time required, or to the fatigue experienced by a man drawing coke by hand.

Inasmuch as an oven can be drawn in not more than 20 min. (a record of 10 min. has been attained), provided the ovens are immediately recharged, there is a substantial saving in heat conserved in the oven and in the time employed in burning off the charge of coke, in addition to the saving of approximately one-half the cost of hand-work in drawing and loading. In other words, the efficiency of each oven is sensibly increased, while the cost of the operation is diminished.

Figs. 1, 2, 3 and 4 show the coke-drawing machine in position in front of a row of ovens and ready for operation. The machine operates smoothly; performs its work easily without jar; can be driven by steam or electricity; is capable of withstanding hard usage; and is compact and simple. The well-braced frame of iron, cast in one piece, is supported on a truck having four wheels. Within the frame are the necessary

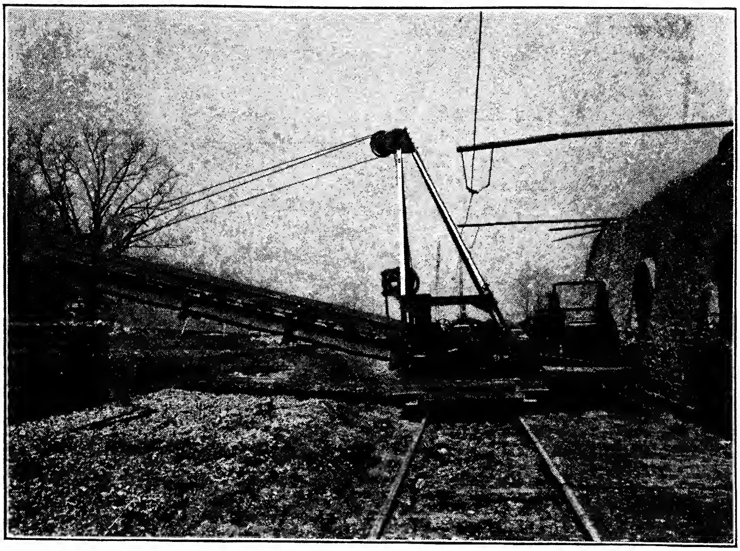

FIG. 1.—SIDE VIEW OF COKE-DRAWING MACHINE, SHOWING CONVEYOR TO CARS.

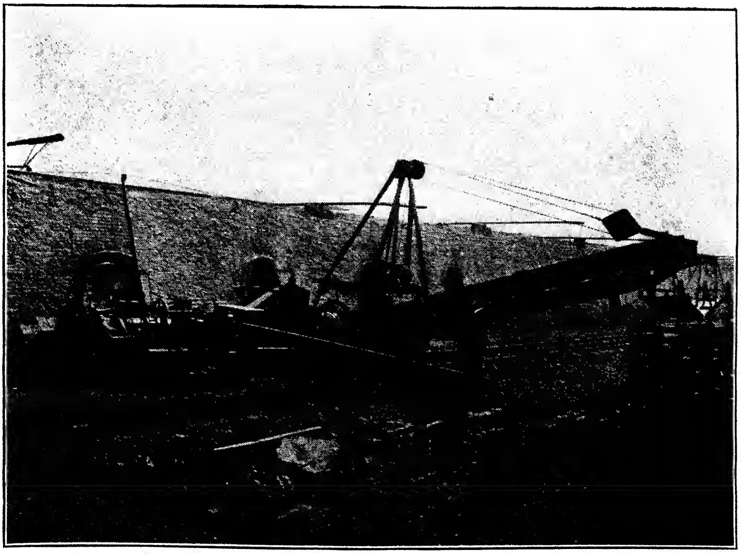

FIG. 2.—SIDE VIEW OF COKE-DRAWING MACHINE, SHOWING RAM AND CONVEYOR TO CARS.

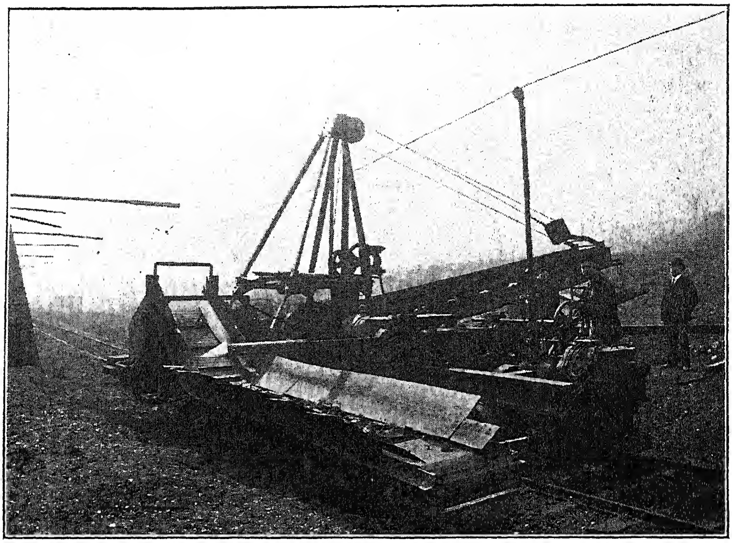

FIG. 3.—END VIEW OF COKE-DRAWING MACHINE, SHOWING RAM AND CONVEYOR IN FRONT OF OVENS.

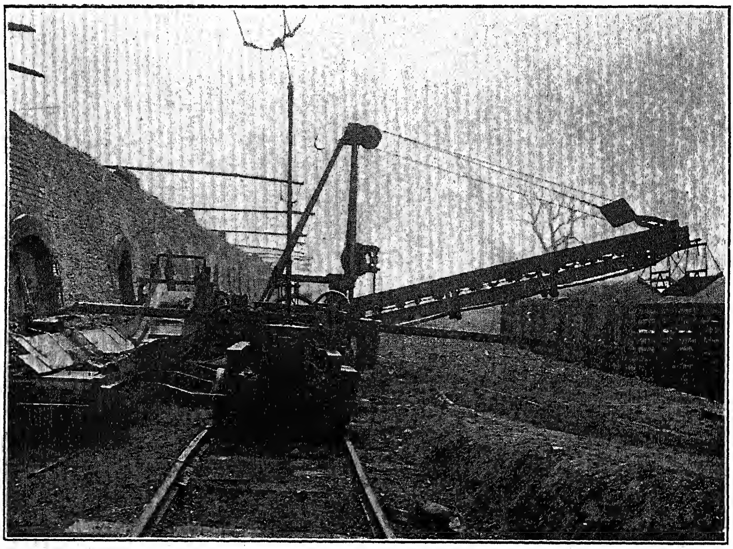

FIG. 4.—END VIEW, SHOWING RAM AND BOTH CONVEYORS.

heavy cut-steel gearings which operate a steel ram equipped at its extremity with a chilled cast-iron shovel, thin at the front and 6 in. thick at the back, which serves as a wedge. The length of the ram, and the power employed, are sufficient to force the ram in under the coke, to the back of the oven. By reversing the motion of the gearing, the shovel is withdrawn from the oven with its load of coke. In other words, the ram acts like a wedge, raising and parting the coke so as to cause it to fall, in the manner stated. The motor, of the street-railway type, is simple and easily operated. The machine can be moved forward or backward on its track, and the carriage sustaining the ram can be revolved on a central axis, which allows the ram to be introduced into the oven at any angle, and thus to reach any part of it. In operation the central portion of the coke is drawn first, and then the ram-carriage is swung on its axis so as to draw the coke on either side of the central line. While it is possible to reach any part of the oven by the arrangement above described, there will always remain in the oven a small quantity of coke, which it is expedient to remove by hand. This is readily accomplished by one man following the machine, who cleans out this remnant and also puts the oven in shape to receive a new charge.

By means of a worm-gear inside of the frame, the machine can be moved back and forth on a standard-gauge track to any desired position in front of the ovens. The coke, when drawn, falls on the conveyor, which is supported on a separate truck, has a separate motor, and is so equipped that it screens the coke from the ash, during conveyance, and delivers it into a railroad car, ready for shipment.

One question will naturally suggest itself to anyone interested in coke-making; namely, does the machine deliver the coke on the cars in as good condition as coke which has been drawn and loaded by hand? Experienced men who have watched the machine under trial at Continental No. 1 freely say that the quality of the coke is as good, and as free from breakage, as that which had been drawn and loaded by hand.

There are in addition the following advantages:

(1) The ovens are watered in advance of the machine by men who do nothing else, and who, therefore, can be trained to use only sufficient water to accomplish the desired result. They

do not have to consider the heat which the hand-drawer must face; and the foreman can accurately determine the amount of spraying which they shall do, in order to insure the use of a minimum amount of water required to deaden the coke. Excessive watering occasions a loss of heat and produces black ends; and use of the machine ought, in this respect, to produce much better results than can be obtained by hand-drawing, in which many men are employed to water the coke.

(2) After the machine has extracted the coke from an oven or ovens (provided the ovens are immediately put into shape for re-charging), the promptness with which ignition takes place is apparent to even the most casual observer. This is in strong contrast to the action of ovens which have been drawn by hand and exposed for 2 or 3 hr., or more, to the cooling action of the air.

An inspection of the working of the machine showed that one hour was ample in which to remove the coke from 3 ovens and put them in shape for the next charge.

The advantages of using the mechanical coke-drawer are summarized as follows:—

(1) There will be fewer black ends, owing to better control in watering-down the coke.

(2) The quality of the coke will be in no way inferior to that drawn by hand.

(3) There will be a substantial economy of labor in drawing and loading the coke.

(4) There will be a considerable conservation of heat and a better efficiency in operating the ovens.

(5) There will be a saving in time; or a corresponding increase in output.

(6) There is no field in which the substitution of a machine for hand labor will be more welcomed, since, in season and out of season, no manual labor is subjected to greater hardship (except, perhaps, in puddling) than in drawing coke from a bee-hive oven.

(7) Any intelligent man can easily and quickly be taught to operate the machine.

A test, recently made by Mr. M. R. Berry, of the West Penn Electric Co., of Connellsville, Pa., on four ovens drawn consecutively, gave the following data for power-consumption:—

Average time of drawing = 16 minutes.
Average kw-hr. consumption, total = 2.2 kw-hr.
Average ampere-consumption on extractor = 30 amperes.
Average extractor-voltage = 170 volts.
Average ampere-consumption of conveyor = 16 amperes.
Average voltage of conveyor = 210 volts.

The sequence of readings for the complete stroke of extractor-arm would be about as follows:—60 ampere momentary demand on reversal at beginning of forward stroke. This drops almost immediately to 35 amperes and gradually down to 26 as extractor-head moves forward. At the end of the stroke the demand rises to 45 amperes, due to extra compression of coke at back end of oven, where there is but small clearance. The current then reverses, and rises to 45 amperes in reverse direction as the rack is reversed, and drops gradually to 22 amperes at end of the stroke.

It seems that the conveyor-current demand should be steady; but, with each reversal of the extractor producing a heavy draft of current, there is a corresponding decrease from about 16 amperes, as a normal for the conveyor, to about 6 amperes. An average of 2.2 units at 2 c. per unit, plus $1 h.p.-demand per month, would make the cost of power alone about 7 c. per oven drawn.

Cost, Per Oven, of Drawing 30 *Coke-Ovens by Machine.*

	Cents.
1 engineer, at $2.25 per day,	7.5
1 helper on larry, at $1.60 per day,	5.33
2 hose-men for watering ovens ahead of machine, at $3.20 per day,	10.66
1 utility man, at $1.60 per day, }	10.
1 helper, at $1.40 per day, }	33.49
Power (as given in preceding paragraph),	7.
Total,	40.49

Over and above the estimate of 40.49 c., a due allowance must be made for interest, depreciation and maintenance of the machine, track, and lines for operating it. This additional cost will vary considerably with different conditions, but an average of 1.5 c. per oven should suffice. On this basis, the total operating cost amounts to 42 c. per oven drawn.

Before the introduction of this machine, the average cost of drawing ovens varied from 75 c. to $1.15 per oven, depending on the location and conditions; the average amount being 92 c.

per oven. The comparison of this amount with the total cost of drawing by the machine described above, shows a net saving of 50 c. per oven, which in an ordinary plant of 400 ovens would effect a total economy of $100 per day.

The test shows an average h.p-demand of 5.1 kw. for the extractor, and of 8.5 kw. for the extractor-arm, while shifting the machine from one oven to another.

There is a great field in this country for a machine to draw coke from bee-hive ovens, and I believe the machine described above is proving a decided economy in the work which it performs.

The Use of High Percentages of Fine Ore in a Charcoal Blast-Furnace.

BY HARRY R. HALL, KENT, OHIO.

(Washington Meeting, February, 1905)

THE proposition to make pig-iron from magnetic concentrates and cobbed ore with charcoal-fuel weighing from 12 to 20 lb. per bushel is, on the face of it, not inviting; but the work that has been done under these adverse conditions may be worthy of record as furnishing a comparison with coke blast-furnace practice under similar conditions.[1]

The record of the furnace-practice is briefly summarized as follows :—the charcoal was made of hemlock, pine, spruce, balsam, maple, beech and birch woods. All the concentrates, containing from 62 to 65 per cent. of iron, would pass $\frac{1}{8}$-in. screen, of which about 34 per cent. would pass an 80-mesh screen. The cobbed ore, varying in composition from 32 to 47 per cent. of metallic iron and from 23 to 32 per cent. of silica, would pass through a 1-in. ring, and of this ore about 25 per cent. would pass a $\frac{1}{8}$-in. screen.

The furnace was blown-in October 20, 1903, with charcoal which was supposed to weigh, when dry, 18 lb. to the bushel. Some charcoal similar to this was stored in the stock-house for about a year, and was then found to weigh 12 lb. per bushel.

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[1] See Mr. Barrows' paper, The Use of High Percentages of Mesabi Ores in Coke Blast-Furnace Practice, *Trans.*, xxxv , pp. 140 and 977.

During the first 10 days of the blast, the furnace produced 362 tons of pig-iron, using 200 bushels of charcoal per ton of iron. From November 1st to 12th, the volume of the blast was increased gradually from 2,808 to 5,460 cu. ft. per minute, with practically no increase of output. The silicon-content of the resultant pig-iron averaged 0.75 per cent., and sulphur about 0.035 per cent. A supply of dry, freshly-burned charcoal was then used, which increased the silicon-content, and lowered the sulphur to less than 0.010 per cent. On November 18th, the furnace made 77.5 tons of No. 2 pig-iron, which was the maximum daily output for the month. For the next 12 days the output varied from 19 to 72 tons per day, apparently dependent upon whether wet or dry coal was used, and independent of the volume of the blast used. During the last 10 days of the month we had the advantage of an experienced charcoal blast-furnace-man, who suggested shorter tuyeres, a smaller bell (our bell was 5 ft. in diameter and stock-line, 7.5 ft.), and condemned bosh-cooling plates. Shorter tuyeres were tried, but no better results were obtained. We did not try a smaller bell, nor was the bosh-construction changed. The output for November was 1,261 tons, on a fuel-consumption of 175 bushels of charcoal per ton of pig-iron produced.

Soon after December 1st, the use of wet charcoal was discontinued. The furnace output then became much more regular. During the month the blast used was 6,000 cu. ft. per min. (engine rev. per min., minimum 36.6, maximum 43.6), the largest quantity ever blown on this furnace, and limited by the excessive loss of ore. The smallest daily output was 66 tons, and the largest 113 tons. The output for the month was 2,777 tons, on a fuel-consumption of 114 bushels (average weight, 17 lb.) per ton. During December the fuel-charge was increased from 72 to 96 bushels, then to 120 bushels, then decreased to 96 bushels, since the latter gave a more even distribution of the charge on the bell. Some months later, a 72-bushel charge was tried, with no change in the working of the furnace. During December the ore-burden varied 30 per cent., depending upon the weight of charcoal per bushel. The charcoal was bought by the measured bushel; consequently, the same weight of fuel could not easily be delivered to the furnace for each charge, since it was measured in the filling-

barrow. During December the ore-charge averaged 15 per cent. of cobbed ore, and 85 per cent. of concentrates. Starting with 66⅔ per cent. of concentrates, the proportion was gradually increased to 90 per cent., with no ill results to the furnace. It was then that I figuratively "held my breath" for 12 hr., while 100 per cent. of concentrates were charged; later, 10 per cent. of cobbed ore were added. Under these conditions the furnace was more inclined to hang up; it turned a shade cold and the slag was not quite of the proper composition. Later, 100 per cent. of concentrates were charged for 12 hr., then returning to the old charge. This time the furnace made the kind of iron desired. After this, 100 per cent. of concentrates were charged for five months, using 1.6 tons of concentrates, the equivalent of 89 bushels of charcoal (average weight, 20 lb.) and 200 lb. of limestone per ton of pig-iron produced; during this period the average daily output was 89 tons of pig-iron; and the loss of ore blown out of the furnace in the form of dust amounted to 6 per cent. of the quantity charged. A screen-test of the ore-dust collected in the dust-catcher showed that all would pass a 20-mesh screen; 2.5 per cent. would remain on a 40-; 10 per cent. on a 60-; 34 per cent. on an 80-; 20 per cent. on a 100-; and 33.5 per cent. would pass a 100-mesh screen.

A screen-test of the concentrates charged into the furnace gave:—all passed an ⅛-in. mesh screen; 24 per cent. remained on a 20-; 31 per cent. on a 40-; 11 per cent. on a 60-; 9 per cent. on an 80-; 6 per cent. on a 100-; and 19 per cent. through a 100-mesh screen.

With charcoal-fuel, 5,625 cu. ft. of air per min. was generally blown (Southwark engine displacement). In April we used 40.3 cu. ft. of air to burn 1 lb. of fuel; in May we used 43 cu. ft., and in June, 44 cu. ft. The same furnace using coke-fuel produced 60 tons of pig-iron per day for a month on a fuel-consumption of 2,220 lb. of Connellsville coke. Blowing the same volume of air on coke as was blown on charcoal resulted in a loss of ore blown out of the furnace amounting to 25 per cent. Increasing the volume of air would not increase the output, since more ore was carried away by the blast. Volatile matter in the charcoal formed a coating on the dust-catcher dirt, making it impossible to moisten it; but, while using coke-fuel, the dirt is collected and re-charged into the

furnace. If the dust-catcher dirt were put into the furnace without wetting, it would all be blown out into the dust-catcher.

With charcoal-fuel the average pressure of the blast from month to month varied from 4.25 to 5 lb. per sq. inch. The pressure was apparently dependent upon the weight of charcoal per bushel, being higher on heavier charcoal. The blast-pressure with good coke was lower than when blowing the same volume of air on charcoal. The maximum daily output of the furnace with charcoal was 113 and with coke 73 tons. A larger quantity of pig-iron would have been obtained had the ore been coarser. Hard blowing increased the loss of concentrates, due to the resultant dust

The impression seems to be widespread that coke is the ideal fuel for making pig-iron, but charcoal ranks first because of its low ash-content and its freedom from sulphur. For instance, compare our month's work, using 1,751 lb. of charcoal and 157 lb. of limestone per ton of iron produced, with that using 2,220 lb. of Connellsville coke and 1,330 lb. of limestone. Charcoal contains 75 per cent. of carbon, and the 157 lb. of limestone per ton of iron will consume about 80 lb. of charcoal, which leaves 1,252 lb. of carbon for reducing the ore, melting iron and slag, radiation, etc. In the case of coke (which was of a high sulphur-content) 1,330 lb. of limestone were used, requiring about 400 lb. of coke, which leaves 1,529 lb. of carbon, available to reduce the ore, etc. These figures are practically accurate, and serve as a rough estimate to show that a charcoal-furnace of the same size as a coke-furnace will produce from 25 to 33 per cent. more pig-iron per unit of time.

The following is a general ratio of hearth-area to daily output of a charcoal-furnace:—a 7-ft. diameter hearth should produce 110; 7.5-ft., 133; 8-ft., 161; 8.5-ft., 192; and a 9-ft., 225 tons of pig-iron per day.

The Magmatic Origin of Vein-Forming Waters in Southeastern Alaska.*

BY ARTHUR C. SPENCER, WASHINGTON, D. C.

(Washington Meeting, May, 1905)

HAVING suggested magmatic waters as the probable agents of vein- and ore-deposition in Southeastern Alaska in a paper entitled, The Geology of the Treadwell Ore-Deposits,[1] it is with particular interest that I note Mr. W. Lindgren's application of the hypothesis of igneous emanations to the gold-quartz veins of Victoria and of California.[2]

After describing the similarities of the veins and of the changes in the wall-rock due to the action of vein-waters in the two regions considered by him, Mr. Lindgren formulates the hypothesis that the veins of this type

> "have been deposited chiefly by 'eruptive after-effects,' in other words, chiefly by hot ascending waters originally contained in the granitic magma and relased from it by decreasing pressure, due to its irruption into the upper parts of the lithosphere. It is quite possible that atmospheric waters may have played a certain part by aiding the precipitation and by effecting certain forms of concentration in the deposits"

There are many reasons for extending this hypothesis to southeastern Alaska. This region and the Sierra Nevada belt of California are undoubtedly parts of one geologic province, throughout which the main events of geologic time are evidenced by identical or closely similar records in the rocks. Our knowledge of the former region is still fragmentary, to be sure; but the origin-dates of the most prominent features of geology have been located in the time-scale, and found to correspond completely with the red-letter dates in the Californian record. In both there are: (1) intense folding and meta-

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[1] *Trans.*, xxxv., 473.

[2] Characteristics of the Gold-Quartz Veins in Victoria, *Engineering and Mining Journal,* March 9, 1905, p. 460.

morphism followed the deposition of strata which palæontologists agree are either uppermost Jurassic or lowest Cretaceous (Mariposa beds of California); (2) intrusion of granitic rocks (mainly granodiorite and diorite) accompanied the later stages of folding or closely followed the plication and metamorphism; (3) after the intruded rocks had solidified, both they and the enclosing formations were fractured; (4) the multitude of wounds were healed by the deposition of vein-fillings, the mineralogy of which corresponds in almost every respect in the two fields; and finally, (5) erosion ensued and was followed by the deposition of formations of Tertiary age.

Reasoning from the above outline alone, is it not to be expected that the origin of the veins in the two regions must be identical, and does it not add strength to the suggested hypothesis that it has been developed and applied independently in two regions geologically so similar?

Students of ore-deposition will wait with keen anticipation a complete exposition by Mr. Lindgren of the data on which his hypothesis is based. My own suggestions concerning the veins of southeastern Alaska are necessarily founded on a very incomplete knowledge of the facts involved, since all of the observations upon which they rest were made during a single summer. The hypothesis here presented, therefore, undoubtedly borders too closely on pure speculation to carry much weight by itself. Nevertheless, none of the data at hand seem to be antagonistic to it, and it is hoped that by stimulating the collection of data having a definite bearing *pro* or *con*, its prematureness may be in a measure compensated.

The most striking feature of geology in the Alaska "Panhandle" is the great dioritic core of the Coast range, a complex of coarsely granular intrusive rocks, which is known to be continuous from near the northern boundary of Washington State to beyond the head of Lynn canal. Outside of this band, many masses of similar rock occur throughout the Alexander archipelago, and likewise in the region back of the coastal barrier in British Columbia.

The wide occurrence of this invading rock has led to the conception that it may exist as an underlying mass throughout a very extensive region, in which the surface formations are mainly metamorphosed sedimentary rocks comprising repre-

sentatives of the different geologic periods from Silurian to Lower Cretaceous.

Metalliferous quartz-veins are found in all parts of the region, though in general they occur less frequently in large intrusions than in small masses of diorite, and are most numerous in the metamorphosed formations which enclose the intrusive rocks. They are quite as numerous away from the bodies of diorite as near them and, in fact, show no distribution relation to the masses of intrusive rock. From the structural features of the veins, there can be little doubt that most of them were formed during a single period of water-circulation which followed not only the invasion of the diorite, but, in fact, the complete solidification of those parts of the intrusive masses now exposed to view.

Seeking to explain the relations observed, and to determine the source of the vein-forming waters, it may be assumed that the deep-seated portion of the magma which furnished the Coast Range diorite remained in an unconsolidated condition long after the complete crystallization of the masses observable at the present surface. Under certain conditions the existence of a deep-seated and widely-distributed magma in any region might be favorable to the production of general fracturing in the solid rocks above it, and the magma itself might well be the principal source of the vein-waters. Leaving the origin of the vein-openings for separate consideration, let us turn to the question of the magma as a source of vein-forming solutions.

If, during and subsequent to the fracturing of the rocks, the abyssal portion of the magma was gradually consolidating, it must have given off large amounts of water; for it is now generally agreed by petrologists that the order of crystallization exhibited by the minerals of the granular rocks can be best explained by admitting the existence of more water in the magma before and during its consolidation than is shown by analysis of the resulting rock. Accepting this, crystallization would be the *sine qua non* for a continuous and sufficient supply of water, which can be properly conceived of as containing in solution all the elements necessary to form the observed veins. Deposition from such magmatic or original waters would be controlled by any or all of such circumstances as decrease of pressure or temperature, metasomatic action on

the country-rocks, and mingling with solutions which might bring about chemical reaction.

The applicability of the hypothesis depends upon,—(1) the existence of the supposed extensive bed of diorite beneath the area in which the veins occur, (2) the possibility that such a mass could rid itself of water freed during the process of crystallization, and (3) the competence of solutions of magmatic origin to produce the results observed.

The first requirement may be assumed to exist in the region under discussion on the ground of probability, while the second and third, which are inherent in all problems of ore-deposition where the instrumentality of magmatic solutions is suspected, can be reasonably inferred from well-known observations. The manner in which water has escaped from masses of rock during deep-seated solidification is not readily arrived at, but, that most magmas must have contained more water than is to be found in their crystallized products, that is to say in the rocks, is reasonably well established and is accepted by such recent writers as J. H. Vogt, J. F. Kemp, A. C. Lane and C. R. Van Hise. The fact that water must have escaped is patent from a comparison of the dryness of the rock with the fairly-presumed wetness of the magma.

As to the ability of magmatic solutions to produce quartz-veins carrying gold and metallic sulphides (sometimes, as in Australia, California and Alaska, with albite and rutile, or with tourmaline) there can be little doubt. During deep-seated solidification, the material dissolved in the magma-water will vary with the progress of fractional crystallization, and, as crystallization proceeds, the mother-liquor, that is to say, the remaining magma, becomes more and more siliceous. For granitic and dioritic magmas, this follows from the fact that the minerals separate essentially in the order of their relative basicity—apatite and magnetite, being followed by mica and hornblende; and these by the less siliceous feldspars; and finally by the siliceous feldspars and by quartz, if there be an excess of silica. During the later stages of consolidation, silica and salts of the alkalies and of lime come to be the main constituents of the solutions. This may be inferred, so far as silica and the silicates are concerned, from the position of quartz and

the siliceous feldspars, orthoclase and oligoclase or albite, in the scheme of crystallization given above.

In general, the solutions escaping from a mass of crystallizing rock would carry with them the greater part of all the highly soluble constituents of the original magma, among which, chlorides, fluorides, carbonates and sulphates may have been present in important amounts, and, if present, certain of these salts would increase the dissolving-power of the waters in respect to silica, the metallic sulphides and gold, so that the magmatic solutions could readily have produced the veins referred to them by the hypothesis. The quotation from Arrhenius given by Vogt[3] bears directly upon this point, as does Brögger's statement[4] of the order of formation of the minerals in the pegmatites of southern Norway, where the so-called mineralizing agents, fluorine, chlorine and boron, do not enter, to any great extent, into the constitution of the minerals formed during the first stages of solidification, but are found in considerable amounts in the minerals formed after the principal mass of the magma had crystallized.

The list of vein-minerals found in southeastern Alaska includes most of those recorded from the Californian mines, but the occurrence of tourmaline is frequent rather than rare, and considerable amounts of rutile are present in a certain set of veins near Juneau and in the Treadwell ores. In both instances the rutile is associated with albite and carbonates of lime, magnesia and iron. The bearing which the presence of tourmaline and rutile may have upon the hypothesis of magmatic waters will be considered in some detail. (For a recent list of localities where ores are accompanied by tourmaline, see *Zeitschrift für Praktische 'Geologie*, vol. xii., p. 66, (1904).

When, in 1895, Mr. Lindgren[5] assigned the vein-forming waters of the Nevada City and Grass Valley districts to surface waters penetrating the dioritic rocks and dissolving from them metallic elements afterwards deposited during the return journey toward the surface, a difficult point to explain was "the

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[3] *Genesis of Ore-Deposits*, by Posepny, and others, p. 644, (1901).

[4] *Die Mineralien der Syenitepegmatitegange der Sudnorwegischen Augit- und Nephe-insyenite*, pp. 148–181, Leipzig, (1890).

[5] *Bulletin Geological Society of America*, pp. 221–224, 1895; also, *U. S Geological Survey*, 17*th Annual Report*, pt. II., p. 176, (1895–96).

absence of fluorine and boron compounds which so often occur in ore-deposits in granitic rocks." The occurrence, in the Juneau region, of tourmaline which contains these elements may be regarded as favoring a source in igneous rocks, and in my belief their presence lends weight to the magmatic hypothesis.

Titanium oxide and albite, occurring as original vein-minerals, may point in the same direction, in the light of Daubrée's conclusions concerning the genesis of the titaniferous albite-veins of the Alps. This distinguished synthesist produced crystals of titanium oxide by submitting titanium chloride vapor to the action of steam,[6] a procedure which was supposed to imitate natural conditions of deposition, indicated by the paragenesis of the three oxides of titanium—rutile, anatase and brookite in the Alpine veins. Daubrée therefore had no hesitation in suggesting "sublimations" as the active agents in forming the veins marked by the peculiar association of the minerals named, with titaniferous hematite, quartz, albite, adularia, calcite, dolomite and siderite, mica, fluorite, tourmaline, etc. In this connection, he refers to the discussion by Élie de Beaumont of the relation between metalliferous veins and volcanic emanations, showing that in his own mind Daubrée regarded the sublimations as related to igneous activity.

Both Vogt and Lindgren[7] suggest that chloride or fluoride solutions, or vapors, have been important factors in the formation of topaz-cassiterite, scapolite-apatite, and tourmalinic gold-copper veins, the importance of which in the present connection is, that rutile is a common accessory mineral in the types of veins enumerated.

Bischoff has shown the efficiency of sodium chloride solutions in transforming potassium feldspar to albite,[8] a fact which suggests the possibility that the metasomatic change of microperthite to albite, which has taken place in the Treadwell deposit,[9] may have been produced by the action of waters carrying common salt.

In the Juneau district the formation of albite as a vein-mineral and as a metasomatic replacement in the wall-rock, is

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[6] *Annales des Mines*, vol. xvi., 4th series, p 130, (1849).
[7] *Genesis of Ore-Deposits*, Posepny, pp. 540–564 and 643–648, (1901).
[8] *Chemical Geology*, Vol. II., p. 410.
[9] Spencer, *Trans.*, xxxv., 505.

natural if the depositing waters were of magmatic origin, because the diorites of the region from which such waters would have been derived are essentially soda rocks. Likewise the presence of rutile in some of the ore-deposits corresponds with unusual amounts of titanite in the intrusive rocks. That chlorine and possibly fluorine were also present in the parent magma may be properly assumed from the presence of abundant apatite in the diorites. On the magmatic hypothesis, either fluorine or chlorine may, therefore, well have taken part in the formation of the quartz-albite-rutile veins. In conformity with the ideas of de Beaumont and Daubrée, which have been especially elaborated along original lines by Vogt and Arrhenius, these and several other elements may play an important rôle in vein-deposition without entering into the constitution of any of the vein-minerals, and it is strongly suspected that sodium chloride may have been an essential component in the vein-forming solutions of this region.

In the veins of the Juneau district, which have not yielded rutile or albite, boron and fluorine are present in the mineral tourmaline, and it is possible that chemical tests may reveal chlorides mechanically enclosed in some of the vein-quartz, as in the case of certain Californian veins investigated by Mr. Lindgren. Unfortunately, proper material for this determination is not at hand, but research along this line will undoubtedly be undertaken in connection with future studies of ore-genesis in southeastern Alaska.

The existence near each other of tourmaline-bearing veins, which, so far as observation shows, contain no albite and rutile, and others containing the latter minerals, without the former, is a feature the bearing of which is still unrecognized. No difference in relative age of the two types can be suggested, all the information at hand going to show the practical contemporaneity of the fractures in which they occur, so that it seems not at all improbable that the depositing solutions were of practically the same nature, the difference in the mineral aggregates in the two sorts of veins depending upon unlike conditions controlling deposition. An indication that this explanation may be true is the fact that the veins containing albite are, in general, those enclosed by igneous rocks which have suffered considerable metasomatic changes due to the vein-forming waters,

while the albite-free veins occur typically in metamorphic sediments, or in igneous masses practically unaltered by the depositing solutions.

The above considerations seem to me sufficient to show that the magmatic hypothesis is adequate to account for the facts in southeastern Alaska. It remains, however, to show the inadequacy of the meteoric hypothesis before the suggestion of magmatic waters can be raised to the dignity of a theory. For the great metalliferous region bordering the Pacific coast, it seems that the true theory of vein-genesis can be fully developed only by establishing, with the greatest possible degree of accuracy, the position which ore-deposition occupies in the geological history of the region. When this has been done, I foresee the probability that a point of fatal weakness, in any attempt to explain the ore-deposits by waters derived from the surface of the earth, will be the impossibility of attributing to the action of downward percolating waters any changes observable in the rocks, though such changes should be recognizable if the ascending waters by which the veins were undoubtedly deposited had been thus derived.

Genetic Relations of the Western Nevada Ores.*

BY J. E. SPURR, WASHINGTON, D. C.

(British Columbia Meeting, July, 1905.)

CONTENTS.

I. INTRODUCTION.

The region here discussed is that part of Western Nevada in which, during the last few years, discoveries of rich gold- and

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silver-ores have been made at Tonopah, Goldfield and other camps. The special studies which have been made of the ore-deposits have chiefly to do with Tonopah and the older camp, Silver Peak, about 25 miles southwest of Tonopah. Other camps in the same region have also been visited.[1]

II. Tonopah.

1. *General Geology.*

Only those features of the general geology which are essential to the understanding of the ore-deposition will here be discussed. Tonopah is situated in a region of Tertiary volcanics, and the study of the general geology has chiefly to do with the nature, period and effects of the different volcanic eruptions. The volcanic rocks comprise andesites, rhyolites, dacites (latites) and basalt. There are also present, Tertiary lake-beds, mostly stratified tuffs derived from the volcanic out-bursts. The structure and succession of these lavas indicate a varied history, comprising many volcanic eruptions, which brought forth showers of ash and pumice, or streams of lava. The volcanic activity was accompanied by movements in the crust, which produced tilting of the rocks and a very intense and complex faulting.

There are grounds for believing, that beneath the Tertiary volcanics of Tonopah, there is an older formation of Paleozoic limestone and intrusive granite. Such formations outcrop both to the south and to the north at frequent intervals. At Tonopah, fragments of limestone and granite are among the blocks which were hurled out from the volcanoes at the time of some of the dacitic eruptions.

The oldest of the Tertiary volcanic rocks is an andesite which I have called the earlier andesite, to distinguish it from a subsequently erupted rock of similar composition. This earlier andesite, wherever found, is decomposed to a variable extent. From microscopic study it appears that the original fresh rock was a hornblende-biotite andesite, the feldspar being typically andesine-oligoclase. In the present altered condition, no actual biotite or hornblende has been found, these minerals being

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[1] I have described these camps in Professional Papers of the U. S. Geological Survey, soon to be issued.

represented by their decomposition-products,—quartz, sericite, pyrite, siderite, hematite and, sometimes, chlorite and calcite. The feldspar is usually altered to quartz and sericite, or quartz and adularia. As a result of the alteration-processes, the whole rock is usually more or less completely altered to an aggregate which is composed of quartz and sericite, usually with some pyrite and siderite, and frequently adularia, kaolin and iron oxides. Chlorite and calcite, though not so common, may be abundant. They indicate a process of decomposition different from the ordinary. As a rule, the rocks may be divided according to their processes of decomposition into two classes: (1) quartz-sericite-adularia rocks,—most abundant and most closely associated with the metalliferous veins; and (2) chlorite-calcite rocks,—not associated with the ores.

The next oldest rock is the later andesite. This is much like the earlier andesite, but is slightly less siliceous. It is often nearly fresh, but in some places it is largely decomposed. The general process of decomposition is usually different from that of the earlier andesite. The phenocrysts, which, larger and more abundant than in the earlier andesite, consist of biotite, augite, hornblende, and feldspar which is predominantly andesine-labradorite. In general the decomposition-products are quartz, chlorite, calcite, pyrite and siderite. The later andesite overlies the earlier andesite and covers up the metalliferous veins which occur in the latter rock.

Younger than the andesites are a series of rhyolitic rocks (rhyolite-dacites or latites). These lavas, differing slightly in composition among themselves, were erupted at different times during a single general period of volcanic activity. In the complete report upon this district,[2] several of these eruptions have been distinguished and separately mapped, but only three of these need here be mentioned. One, which I have called the Tonopah rhyolite-dacite eruption, is a dense, glassy rock occurring in intrusive masses and thin sheets. This rock contains porphyritic crystals of biotite, feldspar and quartz in a glassy ground-mass. The most common feldspars are orthoclase and andesine-oligoclase. Near its intrusive contacts, this rock is often greatly silicified, the alteration having evidently been

[2] Geology of the Tonopah Mining District, Nevada, by J. E. Spurr, *Professional Paper No. 42, U. S. Geological Survey* (1905).

accomplished by hot-spring action succeeding the intrusion. Secondary quartz, pyrite, and, sometimes, siderite are the chief results.

A dacite of later age and of somewhat different character is the rock which forms the hills around Tonopah. These eminences represent the columns of lava which rose from the abysmal regions to the surface. Near the contacts of these necks the intruded rocks are usually hardened and silicified and the cracks are coated with chalcedony.

A few of the volcanic necks consist of white siliceous rhyolite (Oddie rhyolite) of nearly the same age as the dacite necks. This rhyolite has a micro-granular ground-mass of quartz and feldspar, with porphyritic crystals of coarse quartz, orthoclase and occasional plagioclase and biotite.

2. *Mineral Veins.*

(a) *Veins of the Earlier Andesite.*—The most important veins of the Tonopah district are in the early andesite and do not extend into the overlying rocks. Where the early andesite is not exposed at the surface, the later rocks form a capping to the veins. This fact shows plainly that the veins were deposited before the eruption of the later andesite and immediately after that of the earlier andesite; indeed, there is every evidence that they were formed by ascending hot waters succeeding and connected with the earlier andesite intrusion, and that these waters had become inactive by the time of the later andesite. The openings, which afforded channels for these ascending waters, were sheeted zones in the rock. The rock was complexly fractured, apparently soon after cooling, and certain zones of maximum fracturing became the chief circulation-channels. These fractured zones have become veins, largely by a process of replacement of the rock. That the mineralizing agency was water is evident from the character of the vein and the nature of the alteration of the wall-rock; that its action was probably connected with the earlier andesite eruption is shown by the fact that it followed this, and, at least so far as mineralizing activity was concerned, was of limited duration, for its effects have not been discovered in the succeeding later andesite. It appears probable, therefore, that the mineralizing agents were volcanic waters, such as are usual among the after-

effects of volcanic outbursts; also that they were hot and ascending.

In the primary sulphide ores, lying below the oxidized zone, the principal gangue-minerals are quartz, adularia and some sericite, with occasional carbonates of lime, magnesia, iron and manganese. The ore-minerals consist of sulphides of silver, antimony, copper, iron, lead and zinc, in the form of stephanite, polybasite, argentite, chalcopyrite, pyrite, galena and blende. A considerable quantity of silver selenide is also present, and gold in a yet-undetermined form. The remarkable thing about the metallic contents is the relative scarcity of the common elements and the abundance of the rarer ones.

The depth of oxidation in these veins is very irregular, depending upon the relative perviousness of the overlying rocks. In the oxidized zone, horn silver is abundant, with some bromides and iodides. Free gold has been deposited. The presence of limonite and black oxide of manganese is characteristic.

Pyrargyrite or ruby silver, and argentite frequently occur, coating crevices in primary ore. In these cases they are evidently of secondary deposition.

(b) *Veins of the Tonopah Rhyolite-Dacite Period.*—The veins connected with the earlier andesite constitute the principal class at Tonopah, but veins belonging to a later period are frequently found. These later veins are associated with the Tonopah rhyolite-dacite intrusions and are dependent upon them, similarly as the earlier andesite veins are dependent upon the earlier andesite. The veins of the Tonopah rhyolite-dacite period are characterized by irregularity and lack of persistence, though their size may locally be considerable. The veins are barren or contain small quantities of gold and silver, except locally, where rich bunches of ore may occur. A characteristic of the rhyolite-dacite veins, to which there are, however, numerous exceptions, is the greater ratio of gold to silver in them as compared to that in the earlier andesite veins. These rhyolite-dacite veins are also plainly the result of ascending hot waters. The lack of definition and persistence, as compared with the veins in the earlier andesite, shows, that at the time they were formed, no definite fracture-zones were available as channels.

(c) *Veins Dependent Upon the Oddie Rhyolite.*—In one of the

rhyolite volcanic necks (Mount Ararat) veins of a different character from those previously described have been formed. Near the contact of the rhyolite plug with the older rocks, the rhyolite is peculiarly brecciated, showing great blocks jumbled together, with, however, a rhyolitic matrix between. The dim outlines of these blocks, and the nature of the matrix, show that the breccia was formed when the lava was only partly rigid and in the process of cooling. This brecciation is confined to the zone near the contact. Many sharp fractures, chiefly parallel to the contact, are present in the rhyolite. These have been filled with vein-material, consisting of quartz and ferruginous calcite containing some manganese carbonate. This gangue-material contains a little gold. These fissures and fractures plainly resulted from the continuation of the driving-upward of the plug after consolidation was practically complete. The vein-fillings are the result of ascending hot waters which followed the channels thus opened, and cemented them.

A consideration of these veins and their wall-rocks does not afford evidence of the mineralizing waters having contained anything beyond silica, lime and magnesian carbonates, and a trace of gold. The presence of iron is in contrast with the probable absence of iron in the waters which produced the veins in the earlier andesite.

(d) *Alteration of Wall-Rocks.*—In the altered phases of the earlier andesite there are all transitions between the typical quartz-sericite phase, in which calcite and chlorite are not abundant, and the typical calcite-chlorite phase, in which quartz and especially sericite are decidedly subordinate. Hence it has been concluded that these different phases are due to the chemical effects of the same mineralizing waters, which differed in nature as they penetrated to a greater and greater distance from the circulation-channels. Along these channels, which became veins, the rock was transformed by the deposition of silica, sulphides of silver, antimony, etc., gold and selenides. The soda and magnesia, and part of the lime and iron, were removed. In the wall-rock near the vein, lime, iron, magnesium and soda have been replaced by silica and potash. In the rocks more remote from the vein-channels, though the alteration has been complete, there has been no very great increase or decrease in the original elements.

From a study of these different effects of the mineralizing waters, it has been concluded that they were charged with an excess of silica and potash, together with silver, gold, antimony, arsenic, copper, lead, zinc, selenium, etc. They were notably deficient in iron, but contained carbonic acid and sulphur, as well as some chlorine and fluorine. The presence of the two last-named gases is shown by some probably original silver chloride and by the presence of muscovite in the gangue, a mineral which is believed to crystallize almost invariably in the presence of fluorine.[3]

The later andesite is not altered as much as the earlier andesite, but is, however, locally greatly decomposed. From a study of the nature of this alteration, the conclusion has been drawn that the waters which produced it were highly charged with carbonic acid and sulphur, and that they contained magnesia and iron, and also probably lime, in considerable quantity. They were, clearly, hot-spring waters, as is shown by the excessive carbonation and sulphuration, as well as the formation of sericite and talcose materials, uralite, chlorite, serpentine, zeolites, etc. Their chemical composition was quite different from that of those waters which altered the earlier andesite. From a study of the localization of the decomposition of the later andesite, it seems likely that it was due to the influence of solutions following the contacts of later intrusive rhyolitic rock.

(e) *Source of Mineralizing Solutions.*—The waters, which produced the veins and the rock-decomposition in the earlier andesite, were rich in silica and potash and poor in the other common rock-forming elements. They seem to have directly followed the earlier andesite eruption. Those that altered the later andesite were rich in magnesia, lime and iron, and low in silica and the alkalies; and they seem to have followed the eruption of rhyolitic rocks, especially the Oddie rhyolite. Both were hot-spring waters, which differed in their composition as much as the rocks which they accompanied. There is an apparent antithesis in each case between the composition of the erupted rock and the accompanying hot solutions. The

[3] Doelter, *Chemische Mineralogie*, p. 161; and Brauns, *Chemische Mineralogie*, p. 247.

earlier andesite, a rock of intermediate composition, was followed by the advent of waters rich in the elements characteristic of extremely acid rocks. The eruption of the Oddie rhyolite, a very siliceous rock, was followed by the advent of waters rich in elements characteristic of basic rocks and poor in the elements represented in the rhyolite. The exact explanation of this antithesis is a matter for future study.

There are two possible explanations of hot springs; one is that they are due to atmospheric water which has sunk down from the surface to such a depth that it becomes highly heated and then rises again; the other is that they are due to water which forms a part of the molten material in the earth's interior, and which is concentrated and separated from the magma upon the cooling of a molten mass. Lavas which cool at the surface give off vast quantities of water-vapor; and the phenomena of contact-metamorphism, especially that connected with siliceous rocks, show that, in depth, similar water-vapor is expelled from cooling rock. It seems, therefore, impossible to escape the conclusion that, at least some hot springs, the after-phenomena of volcanic activity, are due to magmatic water.

In the arid Nevada region there are, as a rule, no flowing surface waters, the whole supply emerging from the ground as springs. These springs may be either warm or cold. The cold springs usually show two characteristics which indicate that they are of vadose or atmospheric origin: (1) they fluctuate with the season, and (2) they become more numerous in regions of greater precipitation and rarer in the more arid portions. The hot springs, however, so far as the writer knows, do not show these characteristics. They are notably associated with areas of volcanic rocks and they are often very vigorous in the heart of an arid region.

Volcanic activity has lasted in this province from the beginning of the Tertiary to within a few hundred years ago, but many of the hot springs which accompanied or followed the different manifestations of volcanic activity are now extinct. At Tonopah, waters ascending after several of the volcanic eruptions, mineralized and altered the formations through which they passed, and became extinct in a relatively short space of geologic time. It is difficult to explain the totally different composition of the waters of the different periods on

the hypothesis that they were of atmospheric origin, and the antithesis pointed out between the contents of waters of different periods, and the composition of lavas which they followed, is equally difficult to account for on this hypothesis. A third consideration is the peculiar combination of materials in the waters which produced the veins of the earlier andesite, especially the presence of unusually large quantities of the rare metals silver and gold, and unusually small ones of the common metals copper, lead, zinc and iron. Plainly some process of separation and concentration has furnished the noble elements contained in the mineralizing waters, separating them from the baser metals. A view concerning this same problem at the Comstock, expressed by von Richthofen,[4] appeals to me as an explanation of the Tonopah ores also. Von Richthofen pointed out that the volatile materials, chiefly fluorine, chlorine and sulphur, given off during solfataric action, would extract, from the cooling rock, metallic substances of much the same character and proportion as those present in the Comstock lode, while ordinary waters would furnish primarily the more abundant metals, such as iron and manganese, and only small amounts of silver and gold.

(f) *Summary of Genesis of Tonopah Ores.*—The considerations pointed out appear to indicate the following conclusions.

The Tonopah district was, during most of Tertiary time, a region of active volcanism, and probably after each eruption, certainly after some of them, solfataras and fumaroles, succeeded by hot springs, thoroughly altered the rocks in many parts of the district. At the surface, during these periods, the phenomena of fumarolic, solfataric and hot-spring action were similar to those witnessed to-day in volcanic regions; but the rocks now exposed were at that time below the surface. The veins have cemented the conduits which were formed by the fractures due to the heavings of the surging volcanic forces below, and along which, gases, steam and finally hot waters, growing gradually cooler, were expelled, relieving the explosive energies of the subsiding volcanism. The water and other vapors, largely given off by the congealing lavas be-

[4] Cited in *Monograph, U. S. Geological Survey*, vol. iii., pp. 19–20 (1882).

low, carried with them, separated and concentrated from the magma, metals of such kind and of such quantity as are present in the veins, together with silica and other materials. The nature of the metallic minerals in the veins is believed to have depended largely upon the particular magma whence the emanations proceeded.

III. Districts Near Tonopah and Similar to It.

1. *Gold Mountain.*

The mining-district of Gold mountain, 4 miles south of Tonopah, has been prospected for several years, but has not developed into a camp of any importance. The rocks here are rhyolite, rhyolite breccia and tuffs, containing fracture- or breccia-zones, which have been transformed into veins by the action of circulating waters. The vein-material is quartz, often chalcedonic, and the metallic mineral chiefly pyrite, which sometimes contains gold, and sometimes silver. In some cases the veins contain gold only, while in others considerable silver is also present. Some of the richest ore is oxidized and occurs in pockets near the surface. From such ore, shipments have been made; but most of the veins are of low grade.

The rocks at Gold mountain are similar to the rhyolite-dacite series of lavas, breccias and associated tuffs at Tonopah; and the characteristics of the Gold Mountain veins are similar to those of the rhyolite-dacite veins at Tonopah. In both cases the veins, while they are locally strong, have not the regularity or persistence of the earlier andesite veins.

2. *Goldfield.*

I have visited Goldfield, about 24 miles south of Gold mountain, but I have not yet studied the geology thoroughly. The rocks, chiefly volcanic, consist of rhyolites, rhyolite tuffs, andesites and basalts, all probably of Tertiary age. One andesite, examined microscopically, resembles the earlier andesite at Tonopah; and a specimen of basalt resembles the basalt of that district. The rhyolite also resembles the rhyolite of Gold mountain. The ores occur in both rhyolites and andesites, showing that the mineralization occurred subsequent to the

eruption of both lavas. It is therefore possible that the Goldfield deposits are identical in origin with the later series of veins at Tonopah, which accompany the Tonopah rhyolite-dacite, although at Goldfield these veins are of vastly greater economic importance.

There is also a resemblance in the physical characteristics of the later Tonopah veins and the ore-bodies at Goldfield. In the latter, however, the quartz-masses are still more irregular: the outcrops being roughly elongated, nearly circular, or crescentic. The quartz is gray and jaspery, and is due to the silicification of the volcanic rock, which is undoubtedly the work of hot springs. Had the rocks been strongly fractured, we should have had more definite veins, like those of the earlier andesite at Tonopah.

The greater part of one of these quartz reefs at Goldfield contains little or no gold, although pyrite is disseminated throughout it. Frequently, however, ore-shoots of relatively small size occur, which are difficult to distinguish, except by assaying, from the barren portion. It seems probable that these pay-shoots represent the main channels of circulation, while the siliceous casings are the result of water, soaking through the adjacent rock. The values of the ores are chiefly, sometimes entirely, in gold; but in some cases considerable silver has lately been found.

The sulphide ores lying beneath the oxidized surface ores contain tetrahedrite, which is highly auriferous. Tellurium is present, probably in the form of gold telluride. Bismuth sulphide is not uncommon. Free gold also occurs in these sulphide ores. In the gangue, barite is common, but not abundant.

3. *Bullfrog and Kawich.*

Since the opening up of Goldfield, more than a year ago, a number of promising new fields have been discovered in the neighborhood, especially to the south and east. Chief among these, perhaps, are the Bullfrog and the Kawich districts, the former of which is 60 miles southeast, and the latter 72 miles east, of Goldfield. I have not yet visited these camps, but from personal correspondence I have obtained some idea of their nature. Mr. Oscar Rohn has sent photographs, samples and descriptions of the Kawich district, which indicate for this

camp a close analogy to Goldfield, the ore-bodies occurring in similar rocks and being of the same character. Mr. Rohn reports that one of the principal formations at Bullfrog is rhyolite and rhyolite-breccia, which he regards as equivalent to lavas of the Tonopah district. The veins occur, in part at least, along fault- or fracture-zones in the volcanic rock. The gangue is chiefly quartz, and the values are gold and silver.

IV. Comparison of the Tertiary Nevada Ores with Those of Other Regions.

Among the nearest analogies to Tonopah yet described elsewhere, are the contiguous mining-districts of Pachuca and Real del Monte, in Mexico.[5] These districts are similar to Tonopah in character and age of the wall-rocks (Miocene andesites); in the nature of the alteration of the rock near the veins (silicification near the veins, propylitic alteration farther away); in the structural character of the veins (splitting and reuniting); in the general character of the ores (both oxide and sulphide), and of gangue (though adularia as a gangue material and selenides as ores have not been recognized at Pachuca); and in the occurrence of the rich ores in bonanzas, which seem to be due to the intersection of transverse fractures with the main vein-zone.

Many other deposits in Mexico, which have not been fully described, seem, from their recorded characteristics, to be closely similar to Tonopah.[6]

Pachuca is about 2,000 miles southwest of Tonopah, but an analogous deposit lies 150 miles to the northwest,—the Comstock. The Comstock is similar to Tonopah in respect of the character and age of the rocks in which the lode lies (Tertiary andesite) and their "propylitic" alteration; in the nature of the gangue and ore; and in the occurrence of the rich ore in irregular "bonanzas." The chief distinction is that the Comstock consists of a single very strong lode, while at Tonopah there are a number of small ones.

Another region having many striking peculiarities in common with Tonopah, lies about 400 miles due north of it,—the

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[5] Aguilera and Ordoñez, *Boletin del Instituto Geologico de Mexico*, Numeros 7, 8 and 9 (1897).

[6] J G. Aguilera, *Trans.*, xxxii., 513 (1902).

districts of Silver City and Delamar in southwestern Idaho.[7] These districts are similar to Tonopah, viz.:—(1) the ores occur in Tertiary volcanics and are probably in both cases post-Miocene in age; (2) to a striking degree in the character of the ores and gangue materials; (3) in the structural characteristics of the veins, which form a group knit together by branches; (4) in the general character of the alteration of the wall-rock; and (5) in the occurrence of the rich ores in irregular "bonanzas." The chief difference is that, in these Idaho districts, the wall-rocks are mainly rhyolite, and not andesite.

V. Characteristics and Significance of the Vein-Group.

The different mineral districts, mentioned above, exhibit a definite group of veins, characterized by the following features: they occur in Tertiary volcanic rocks of similar character in the different localities, being chiefly Miocene andesites or rhyolites. They constitute strong masses or veins which have as gangue essentially quartz with frequently a little calcite, while adularia, barite, rhodochrosite or rhodonite may also be present in limited quantity. The ore is characteristically a silver-gold ore, silver being usually predominant in the values in varying proportions, though the relative value may be reversed, and in some extreme cases either metal may occur with little admixture of the other. In any case, the abundance of silver or gold, or both, in reference to lead, zinc, iron, etc., is characteristic. Silver sulphides (especially argentite, also stephanite and polybasite together with ruby silver), and gold, (probably largely in a free state), are distinguishing features in the great majority of cases. Tellurides and selenides may also be present. Pyrite, blende, chalcopyrite and galena are usually present in varying quantities. Where they become predominant the vein becomes relatively low-grade. Tetrahedrite, stibnite and bismuthinite are also known to occur. The wall-rocks are much altered to quartz, sericite, chlorite, calcite, epidote, pyrite, etc., and sometimes to adularia. Frequently the rocks nearest the veins are chiefly altered to quartz and sericite; those farther away to the softer "propylitic" alteration,

[7] Lindgren, Waldemar, *20th Annual Report U. S. Geological Survey*, pt 3, pp. 107–189 (1898–99).

consisting of calcite, chlorite, pyrite, epidote, etc. The rich ores occur in irregularly outlined portions of the lode called "bonanzas," which are of limited extent, both horizontally and vertically, and are believed to have arisen as a consequence of the irregular intersection of transverse fractures or fissures with the main vein-channels.

Unquestionably, the close relation among the different mineral districts mentioned, shows a metallographic province, which, in this case, coincides with a portion of a petrographic province.[8] It is probable, indeed, that the co-extension of the metallographic and petrographic provinces is greater than thus established. At many points along the belt of the petrographic province in the Andes of South America,—for example, in Peru,[9]—veins are reported to have, so far as can be made out, a mode of occurrence, age and composition, similar to those of Mexico.

In that better-established portion of the metallographic province which comprises Mexico and Nevada, the ores occur in Miocene andesites in a great majority of cases. In occasionally recurring cases they appear in Miocene-Pliocene rhyolites which succeeded the andesites. The ores are believed to be due to the after-actions of the eruptions, in the form of fumaroles, solfataras and hot springs. Moreover, since these manifestations follow all volcanic eruptions, it is probable that the metals deposited by the after-processes owe their nature and amount to an unusual proportion of them in the magma with which they are genetically connected.

VI. Silver Peak Quadrangle.

Of quite a different class of ore-deposits from that described in the preceding pages are those of the Silver Peak quadrangle, the northeastern corner of which is only about 10 miles west of Tonopah. The deposits of this quadrangle have been made the subject of a Professional Paper, to be published by the U. S. Geological Survey.

1. *General Geology.*

(a) *Stratified Rocks.*—Paleozoic limestones with slates and some quartzites are well represented in the area of the Silver

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[8] Spurr, J. E., *Trans.*, xxxiii., 332–3 (1903).

[9] Fuchs et de Launay, *Gîtes Métallifères*, vol. ii., p. 829 (1893).

Peak quadrangle. They belong entirely within the Cambrian and Ordovician eras. Most of our knowledge of the Paleozoic strata is due to the work of Messrs. Turner, Walcott and Weeks, of the U. S. Geological Survey. The known fossils show the presence of strata belonging to the lower Cambrian, the upper Cambrian and the Ordovician. The rocks, however, are characteristically considerably folded and faulted, and frequently metamorphosed. The series, which is several thousand feet thick, presents no very striking and constant lithologic differences. The detailed stratigraphy and structure, therefore, are still in some doubt.

In the district where the principal gold-mines are situated, near Silver Peak village, there is, below the fossiliferous Cambrian, a series of considerable thickness consisting of limestones and slates, with some dolomitic marble beds. This series has been intruded by numerous alaskitic sheets and by quartz-veins. (Alaskite is a granitic rock composed essentially of quartz and alkali feldspar.) It has become largely schistose and gneissic.

No sedimentary rocks intermediate in age between the Ordovician and the probable Eocene have been found within the area of the quadrangle, but there are extensive and thick deposits belonging to the Tertiary. These Tertiary deposits flank the edges of the mountains and underlie in part, at least, the Pleistocene veneer of the valleys. They consist of soft shales, sandstones, marls, tuffs, volcanic breccias, etc., with interbedded layers of andesitic and rhyolitic lava. The thickness of the whole accumulation is very likely several thousand feet.

(b) *Granitic and Aplitic Rocks.*—Granitic rocks, intrusive into the Paleozoic strata, are well represented in the quadrangle, especially in three chief areas: in the northeast corner near Lone mountain; on Mineral ridge near Silver Peak village; and in a long belt running northwesterly across the southern part of the quadrangle. In the first-named region, near Lone mountain, Mr. H. W. Turner has found that the granitic rocks are chiefly true granites, composed of alkali feldspar and quartz, with some biotite and muscovite. The feldspar includes orthoclase, microcline and albite.

In Mineral ridge, the interbedded slates and thin limestones have been thoroughly injected by siliceous granitic rock, mostly

along the stratification, forming chiefly interbedded, more or less lenticular bodies, and often penetrating the intruded rock thoroughly and altering it to a schistose or gneissic condition. The prevalent phase of the intrusive rock is alaskite or quartz-alkali feldspar rock, having a granular texture like that typical of granite, which very frequently becomes coarser or finer (pegmatitic or aplitic). A frequent, but not common, facies of this alaskite is a siliceous biotite-granite like that at Lone mountain. On the other hand, the alaskite passes, by gradual transitions through a diminution of the feldspar, into pure quartz-veins (dikes), which have very much the same chemical and genetic relation to the alaskite that the alaskite has to the granite. The alaskite consists almost wholly of quartz and feldspar, the chief species of the latter having been determined as orthoclase, microcline and oligoclase-albite.

The granitic masses, studied by Mr. Turner in the southern part of the quadrangle, show a variety of different phases. In composition the rock varies from normal granite to alaskite on the one hand, and to quartz-monzonite or granodiorite on the other, the proportions of lime, soda and potash being variable.

In connection with the granitic areas near Lone mountain and in the southern part of the quadrangle, there are numerous aplitic dikes which clearly represent the later facies of the intrusions. They are mostly quartz-feldspar rocks or alaskites, more siliceous than the related granites. At Mineral ridge this rock is the predominant type, but in the other regions it is subordinate to the granite proper. In many phases of these alaskitic rocks a tendency is seen, under the microscope, for the feldspar and quartz to segregate in bunches, which are irregular or more frequently elongated. These segregations increase in size until they are conspicuous to the naked eye, and by further enlargements quartz masses (veins), often feldspathic, are formed. Such granitic and magmatic quartz is found in all the granite areas, but in the siliceous alaskitic area of Mineral ridge it occurs in great quantities, in thick veins or lenses. The various closely related phases of the granitic intrusions are regarded as variations from a single general granitic magma.

It is probable, also, that the different bodies present represent essentially a single period of intrusion. In the Silver Peak quadrangle the granitic rocks were intruded subsequent to the

deposition of the Paleozoic strata and previous to the Tertiary sediments and lavas. The date of their intrusion is, therefore, post-Ordovician and pre-Tertiary. A short distance north of the Silver Peak quadrangle granitic rocks similar to those at Silver peak are probably intrusive into Triassic and Jurassic strata at several points in the Pilot, Excelsior, Ellsworth and Star Peak ranges.[10]

The work of Mr. Turner has shown that the granitic rocks, in the southern part of the Silver Peak range, cross Fish Lake valley, which lies west of the range, and are represented in the White Mountain range, which is separated from the Sierra Nevada only by Owen's Valley. This adjacent portion of the Sierra Nevada is made up almost wholly of granitic rocks, consisting mainly of granodiorite and granite, and the date of their intrusion has been fixed as in the epoch known as post-Jurassic.

It appears probable, therefore, that the granitic rocks of the Silver Peak quadrangle and of various other ranges of western Nevada are similar in general nature, age and origin, to the granitic rocks of the Sierra Nevada, and are late Jurassic or early Cretaceous in age.

(c) *Dioritic Rocks.*—Small dikes of diorite are abundant in the Silver Peak region. They are almost always more or less altered, sometimes completely. In their fresh form they consisted essentially of feldspar and hornblende in varying proportions, but by alteration they have become a mass of secondary products. They are thus conveniently designated by the field-name of greenstones. The alteration products include chlorite, quartz, calcite, zeolites, epidote, zoisite, kaolin, talc, biotite, etc.

These dioritic rocks appear, from Mr. Turner's mapping, to be associated with the areas of associated granitic rocks. In point of age the dioritic rocks are always younger than the granitic rocks, which they frequently cut. When they occur associated with the aplitic rocks (alaskites) they are also younger than these, and, as Mr. Turner has found, they are younger than the quartz-veins of Mineral ridge, which I have determined to be the siliceous extreme of the alaskitic injec-

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[10] J. E. Spurr, *Bulletin No.* 208, *U. S Geological Survey*, 2d ed. (1903), pp. 102, 103, 109, and G. D. Louderback, *Bulletin of the Geological Society of America*, vol. xv., pp. 317–336 (1904).

tion. These greenstone-dikes are older than the Tertiary rocks, since they are not found in them. Therefore, the only direct evidence of their age is that they are post-Ordovician and pre-Tertiary. The apparent association with the granitic areas, and the limited quantities of the diorite, in habit and amount approximating those of the alaskites, suggest, however, that the dioritic rocks may be a later manifestation of the granitic intrusions.

(d) *Tertiary and Quaternary Lavas.*—In the area under consideration, lavas were erupted in large quantity during most of the Tertiary, and the volcanic activity continued into the Quaternary. Our knowledge of the Tertiary lavas of the Silver Peak region is entirely the result of the work of Mr. Turner, who has mapped the different rocks separately and has distinguished and studied rhyolites, andesites, basalts and some dacites. These lavas seem to have been repeated at different periods.

2. *Mineral Veins.*

(a) *Genetic Relations of the Ores of Mineral Ridge.*—The auriferous quartz-ores of Mineral ridge are economically the most important in the quadrangle, and some of the mines here have had a considerable production. The Drinkwater mine, with some adjacent mines, make up the most important group.

The typical auriferous quartz of Mineral ridge is white and crystalline and, under the microscope, it is seen to be crowded with liquid inclusions. Its appearance is that of the characteristic gold-quartz found in so many districts in the world. Occasionally, this quartz contains original muscovite, and, rarely, original chlorite crystals. Contemporaneous sulphides are sparsely disseminated, principally pyrite, more rarely galena. Occasionally, copper pyrite has been observed. The quartz throughout contains gold and a little silver, the proportion of the latter to the former being about 1 to 100. The gold, finely disseminated in a free state through the quartz, is also contained in the scattered sulphides. It is estimated that about 87 per cent. is in the free disseminated form and the remainder in sulphides. The gold-values are irregularly concentrated into certain groups of quartz lenses and certain lenses within these groups. Thus, in certain portions, it is high grade, while in others it is low grade or nearly barren.

The quartz lenses are intimately associated with alaskite intrusions, one not occurring without the other. Petrographically, typical quartz and typical alaskite form two ends of a rock series, between which every gradation is abundantly represented. The alaskite becomes quartzose and passes to a state in which it contains quartz blotches and veinlets, thus gradually passing over into typical vein-quartz. Nearly every quartz lense, which has been mined or prospected, shows, in places, considerable feldspar mixed with the quartz. As a rule, the gold-content rapidly decreases with increasing feldspar, although occasionally feldspar-bearing rock carries good values. In one place, primary free gold has been found in pegmatite.

It was long ago recognized that granitic rocks (which family includes the alaskites) had originated from magmas essentially different in nature from those which form the more basic plutonic rocks and from those which produce surface lavas. This recognition was due to the discovery of many minerals in granite which cannot be formed from dry melts. Moreover, the relative order of crystallization of the chief granitic minerals is not the order of their relative fusibility, showing that the different materials were not held in the fluid state by the power of heat alone. All the granitic minerals have been artificially formed in the presence of mineralizers, such as water, fluorides, boron compounds, tungstic acid, etc., at a relatively moderate heat, but most of them cannot be formed by cooling from a dry melted mass. The contact-metamorphism, which intrusive granitic rocks exert upon the rocks which they cut, is of such a character as to show the presence of mineralizers. Minerals, like tourmaline, scapolite, muscovite, etc., frequent in the contact-metamorphic aureoles of granites, testify to the emanation of boron, chlorine, fluorine, water, etc., from the consolidating granitic magma. From these and other considerations it is probable that granite has crystallized at a relatively low temperature (compared with that of less siliceous igneous rocks) and that it has remained mobile below the fusing-point of most of the granitic constituents on account of the intermixture of water and other mineralizers. It is likely that water was one of the most abundant and efficient factors in these processes. The quantity of water in a magma has

never been even approximately determined. Scheerer[11] estimated it as between 1 and 50 per cent., but believed that the actual quantity approached much nearer the minimum than the maximum of these figures.

A microscopic study of thin sections of the alaskite of Mineral ridge shows that the crystallization of the rock was slow and interrupted. Two distinct periods or generations of crystals are always represented. In different sections the nature and relative amounts of the minerals belonging to each generation varies greatly, but the following observations apply to all cases:

1. Quartz is usually absent from the first generation, or, if present, is subordinate. In the second generation it is always predominant. In some cases the first generation is made up entirely of feldspar and the second entirely of quartz; but the separation is usually not so marked, some of the feldspar crystallizing with the second generation together with the predominating quartz.
2. Microcline is almost always of the second generation.
3. Albite and oligoclase-albite occur generally in both the first and second generations.
4. Zircon and pyrite are included in the minerals of the second generation, but not in those of the first.

In some cases the rock is almost entirely made up of crystals of the first generation, with the second generation represented in a very subordinate way. Other sections show the first generation only as scattering idiomorphic crystals, with the second generation making up the greater area. In most cases, however, the division is fairly equable.

The chief lesson taught is that the quartz is slightly, but distinctly, younger than the feldspar. It is frequently segregated into irregular chains of grains, which lie between bands of more feldspathic material.

In nearly every section muscovite is present, generally in fine fibers. This muscovite in many cases is plainly an alteration-product which has formed at the expense of feldspar. It is, however, only the feldspars of the first generation which have been thus altered, while those of the second generation

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[11] *Bulletin Société Géologique de France*, 1846–47, 2d Ser., IV., 1, p. 490.

are clear. From a study of numerous sections, three general points concerning the muscovite are learned:

1. The microcline is almost always clear and subsequent to the muscovitization.

2. The quartz is almost always clear and subsequent to the muscovitization, but sometimes encloses fibers and blades of muscovite.

3. The orthoclase and striated feldspars (chiefly albite and oligoclase-albite) are in part muscovitized and in part clear, as is natural from their belonging to both generations.

From this it appears that an incomplete alteration of the feldspar to muscovite took place when the magma was partly consolidated, and before the deposition of the remainder of the magma, which formed the second generation.

These observations show that the crystallization process of the alaskite was slow, so that, in many cases, the magma became filled with contiguous idiomorphic feldspar crystals of the first generation, the interstices between which were filled with residual fluid. The mass, composed of the first generation of crystals, was sometimes rigid enough to be partly cracked and fissured. In these cracks and fissures, as well as in the interstitial spaces between the crystals, the residual fluid solidified. Study indicates that many of the fissures were formed by contraction consequent upon a part consolidation; others seem to have been due to movements brought about by pressure. Thus, the quartz (which makes up always the chief part of the second generation), besides forming as intergranular quartz within the unbroken alaskitic fabric, filled the small fissures, and, collecting in larger masses, formed by itself on a small scale an independent intrusive in nearly the same sense as the alaskitic magma had done. We may logically conclude that this quartz left, upon consolidation, a residue which was still finer-grained and more aqueous.

The ore-deposits are lenses of such magmatic quartz, having various dimensions, as are seen both on horizontal and vertical planes. These lenses are most abundant along certain zones in the intruded formation and overlap on one another. They disappear by wedging or by forking and by splitting into two or more branches. These lenses are original, and not fragments of larger dike-like bodies which have attained their

form as a consequence of shearing. The wedging-out of the lenses is not attended by evidence of unusual movement; moreover, the phenomena of splitting and uniting, forbid the assumption that the form is not primary.

In the chief mines of the district the formation of ore-minerals subsequent to the primary consolidation of the quartz-lenses has usually taken place on a minor scale. Occasionally, however, some later precipitation has taken place. Along cracks in the quartz, frequently near the contact of the quartz with decomposed greenstone (altered diorite) dikes, subsequent vein-material has formed, having a gangue of quartz with some calcite and chlorite, and carrying pyrite and galena. The inference is, that, subsequent to the first or primary deposition of minerals, and subsequent to the intrusion of the diorite, minerals were again deposited along cracks in the original quartz. These minerals are the same as those first deposited, and might be thought to be due to subsequent concentration, the material being derived from the first-formed minerals, and simply concentrated by subsequent circulating waters. This, perhaps, has sometimes been the case, but in one mine (the Mary mine), where the subsequent ore is economically important, the amount of the subsequent deposition is so large as to suggest a fresh and independent supply of material. The phenomena in the Mary mine indicate the work of ascending waters, and these new solutions must have had a composition much like that of the solutions from which the primary ore was deposited.

The close association of the diorite dikes with the quartz-alaskite bodies, and frequently with the subsequent ores, easily leads one to the hypothesis that this subsequent mineralization was dependent on the diorite; but most of the diorite dikes have no later ores in their vicinity, and in the Mary mine, where the largest deposit of subsequent ore was noted, there is no diorite.

The general conclusion is that in this district a series of shaly limestones have been intruded by a highly siliceous alkaline magma. From this magma crystallized principally feldspar and quartz, the consolidation of the feldspar in general preceding that of the quartz. The local phenomena indicate that the crystallization was practically all accomplished subsequent to the injection. This crystallization, however, was

slow, so that the residual quartz was, before its final consolidation, in part drawn off into large and small reservoirs, and so could play the rôle of an independent intrusion. A process of magmatic differentiation by partial crystallization is here proven.

That the lenses are the fillings of cavities, which were present in the schist, is out of the question. The parallelism of the schistosity with the curving walls of the lenses shows that the intrusion filled spaces which it itself created. The lenticular form of these alaskite and quartz masses (including the ore-bodies) is like that of the masses of pegmatite and pegmatitic quartz which have been observed in many places in schists near intrusive granitic contacts. I believe that this form is the normal one for attenuated, aqueous, but still viscous, granitic material, injected into schists. The fact, that the same characterizations apply, as a rule, to the alaskite lenses and the quartz lenses, indicates that the alaskitic fluid must have been much the same as that of the quartz, both being less viscous than that which has formed the true granite, which neither in this quadrangle nor in similar provinces is accustomed to form lenticular intrusions, but rather bold and well-defined dikes and sheets of which the ramifications are easily traceable.

After the last crystallization of the intrusive alaskite and quartz, diorite dikes were injected, and, probably directly afterward, relatively thin aqueous solutions circulated along cracks and produced a subsequent mineralization, not approaching, however, in commercial importance (in this especial district), the primary mineralization. The brittle quartz of the lenses, having been cracked, offered the best channels; and here the subsequent mineralization took place, generally under the relatively impervious schist hanging-walls, indicating ascending waters.

For various reasons it is believed that these subsequent mineralizing solutions represented a residue from the granitic eruptions, more aqueous than that from which the primary quartz crystallized.

(b) *Genetic Relations of the Great Gulch Ores.*—One of the gold-mines of Mineral ridge displays, at first examination, a different character from the general type which has just been discussed. At the Great Gulch mine the general geology is,

for the most part, like that of most of the typical gold-ores of the district. The country-rock is a thin-bedded limestone-slate, considerably altered and schistose. Alaskite and quartz, frequently feldspathic, occur in interbedded lenses in the schist. The ore is auriferous arsenopyrite, which occurs in solid streaks of all thicknesses up to 1 or 2 feet. It is distinctly later than the quartz, but the larger streaks are noticeably associated with the alaskite and quartz lenses, especially with the latter. The hanging-wall of quartz lenses is an especially favorable locality.

Here, fracturing has occurred subsequent to the intrusion of the primary alaskite and quartz. Along the channels thus formed, ascending waters arose and deposited sulphur, iron, arsenic and gold. The period of this mineralization is uncertain from the local data, but from the resemblance of the phenomena here to those of the subsequent mineralization in the Mary mine of the Drinkwater group, it is probable that the ore in the two cases has a similar origin.

(c) *Genetic Relations of the Silver-Ores of Mineral Ridge.*—On the border of the gold-quartz district of Mineral ridge, there are, at several points, ores which contain more silver than gold. The chief of these are at the Pocatello and Vanderbilt mines. The general geology, here, is like that of the Great Gulch mine. Alaskite and quartz lenses are intrusive into a schist which represents an altered shaly limestone. Greenstone dikes and sheets are present, following especially a zone of quartz lenses. Near the greenstone the quartz is frequently cracked, broken and mineralized, and in these cracks the silver-bearing ore has been deposited. The most characteristic mineral is a mixed sulphide and oxide containing copper, antimony, silver and gold.

Here, the schists were first injected by a siliceous magma which crystallized as alaskite and quartz. Basic dikes were subsequently injected, following along the zone of quartz and alaskite lenses, because, here, the fracturing was more easy on account of the greater brittleness of the materials. The intrusion of the diorite produced considerable additional fracturing in the quartz. Along the cracks thus produced, mineralizing solutions circulated and deposited the ore. The whole history indicated is analogous to those cases of mines of the typical

gold-quartz type, which show notable subsequent mineralization, although the character of the ore is somewhat different, in that more silver and copper in proportion to gold are present.

In other deposits on the border of the Mineral ridge auriferous quartz district there are ores which have the same type of metallic minerals as in the Pocatello and Vanderbilt group, but which have been formed by the replacement of a dolomitic marble overlying the schist formation in which the gold-bearing veins lie. In these cases the enclosing quartz of the vein is contemporaneous with the metallic minerals, instead of being antecedent to them, as in the above-described silver-mines.

The mineralization in all these silver-mines seems to differ from the subsequent mineralization described in the case of the gold-mines and prospects, in the presence of more silver and copper; otherwise the facts are not unfavorable for regarding all of this subsequent mineralization as belonging to the same period. I desire to put forth here, as a plain hypothesis, an idea, which has been arrived at, by considering and reasoning from the distribution and character of ore-deposits throughout the quadrangle. The hypothesis is, that solutions of granitic origin have deposited predominantly gold in the granite or in rocks silicified by the metamorphic effect of the granite, and that in or near calcareous or dolomitic rocks, more silver and copper were deposited from the same solutions, the difference being due to the different precipitative influence of the wall-rocks.

(d) *Genetic Relations of the Ores of Lone Mountain.*—The Lone Mountain group of mines are all situated in Paleozoic limestones, dolomites and shales, which have been more or less metamorphosed by intrusion of granitic masses. Metamorphism is most intense near the contact, and fades away gradually as the distance increases. The limestones and dolomites are changed into marble, the shales into hornstones and schists with the development of typical metamorphic minerals. The veins characteristically follow the stratification of the sedimentary rocks. Where they thus occur along bedding-planes, these planes have evidently been the sites of differential movement, producing crushing and greater openness. More rarely, the veins occur in cross-cutting shear- or fault-zones. In one type of ores, the black mineral containing copper and anti-

mony, described in the case of the silver-mines of Mineral ridge, occurs, together with galena and pyrite. This mineral is similar to that which has been described under the name stetefeldtite, and will be referred to under this name in the present article. Copper, silver and gold are present in these ores. The ores of another type are characterized by typical contact-metamorphic minerals as gangue, chiefly epidote and garnet. In this type the metallic minerals are magnetite, specular iron, pyrite, chalcopyrite, galena, gold and silver. In another type a quartz gangue contains a small amount of stetefeldtite, with galena, free gold, and a little copper. In another type the primary ore is galena, now largely altered to carbonate. In general there is a strong likeness among the different ores of this district.

From their location and the nature of their gangue the ore-deposits in the Lone Mountain district are plainly connected with the metamorphism of the sediments produced by the granite. At the time of the granite intrusion, siliceous solutions emanated from the hardening mass and penetrated the surrounding sediments, which were thus re-crystallized and metamorphosed. Such solutions circulated most vigorously along openings which had been formed by the intrusion. These openings were chiefly along bedding-planes, sometimes along cross-cutting shear-zones. Along them, circulating granitic waters deposited quartz and metallic minerals, forming the veins.

(e) *Genesis of the Ores in the Southern Part of the Quadrangle.* —In the southern part of the quadrangle the ore-deposits are all prospects, no paying deposit having yet been discovered. One type of deposits consists of quartz-veins of granitic origin, similar to the primary quartz of the Mineral Ridge district. These quartz segregations, however, are small in quantity and unimportant economically. As in the Mineral Ridge type they contain some gold and very little silver. Other quartz-veins of a different type follow shear-zones in granite. The quartz contains pyrite and gold, and the wall-rocks are altered. The resemblance of these veins in composition to the magmatic quartz-veins of the first type leads to the belief that this second type also is due to siliceous residual solutions, derived from the consolidation of the granite, which have circulated along available channels in portions of the granite which had already

consolidated. Another type of veins occurs in calcareous and argillaceous sediments near the contact of the granite. The gangue is chiefly quartz, the metallic minerals chiefly stetefeldtite, galena, copper, pyrite, etc. The values are chiefly silver with some gold. The country-rock consists of metamorphosed sediments containing typical contact-metamorphic minerals. Veins of this type follow fracture-zones and along such a zone vein-formations may outcrop at intervals for short distances. In one case, veins of this type, in calcareous strata, lie apparently along the same fracture-zone as auriferous quartz-veins of the second type above described, which lie in granite, the fracture-zone crossing from the granite into the intruded rock. The fact that along what seems to be the same great fracture-zone the ores are of different types in the granite and in the intruded sediments, suggests that they were probably formed by the same solutions, and the different character of the veins is assumed to be due to the different character of the wall-rock.

(f) *General Conclusions as to the Origin of the Metalliferous Ores.*

An intimate inter-relation has been recognized for all the metalliferous ores of the quadrangle, and all have been traced to the consequences of one event, namely, the intrusion of granitic rocks into Paleozoic sediments in, probably, post-Jurassic time. This district is favorable for such determinations as have been made, since the granitic masses are small and the grouping of the ore-deposits around them is therefore more evident than in a region like the Sierra Nevada, where the masses of granite are vastly larger.

The ore-deposits may be divided into the two chief groups:

1. Bodies of auriferous quartz, probably separated out in gelatinous form from alaskite, during the process of crystallization, and of the same age and nature as the intergranular quartz of granite and alaskite. In such quartz-bodies gold is in places segregated in commercial quantities.

2. Quartz-veins due to replacement or impregnation of crushed material along fracture-zones by siliceous solutions more attenuated than those described above, and residual from the crystallization of the magmatic quartz of the first type. These solutions were probably in various degrees of dilution by magmatic water. Such deposits were formed chiefly along

movement-zones following bedding-planes in the intruded strata; also in cross-cutting movement-zones in the strata, and to a less degree in the granites. They were formed contemporaneously with the re-crystallization and contact-metamorphism of the sediments under the influence of the granite intrusion. They are more or less typical quartz-veins in the pure carbonate rocks and in the granites, but in the argillaceous rocks the quartz is often intermixed in various degrees with metamorphic silicate minerals, such as garnet, epidote, etc. The metallic elements present are principally silver, gold, lead, arsenic, antimony, copper, iron, etc., in various combinations. There is more gold in the granite, more silver and lead in the intruded strata. In the granite the metallic mineral is mostly pyrite, sometimes arsenical. In the sedimentary strata the characteristic metallic mineral is the altered sulphide, containing silver, copper and antimony, which we may provisionally call stetefeldtite and galena. The different character of the metallic minerals is believed to be largely due to the wall-rocks, which have precipitated certain things from solution. Aside from the quartz the nature of the gangue is also believed to be chiefly due to the nature of the walls.

In all the types of ore-deposits studied, the character of the solutions is believed to have been highly siliceous and alkaline, with mineralizers, such as fluorine, boron, etc., present, but in a limited amount. The presence of gold, silver and other metals is sufficiently explained by the composition of solutions such as described, in which the necessary solvents are present.

VII. Comparison of Silver Peak with Other Ore-Deposits.

Fifty miles northeast of the northeast corner of the Silver Peak quadrangle is the Belmont district, at one time productive, but long since abandoned. The ore-deposits consist of quartz-veins which occur in the immediate vicinity of an intrusive mass of granite. From some microscopic work done by me[12] on this granite, it appears that magmatic solutions have been active, producing quartz and muscovite at the expense of the orthoclase in the intrusive rock, and altering the siliceous limestone of the wall-rock to jasperoid and mica-schist. The

[12] *American Journal of Science*, vol. x., p. 355, (November, 1900)

mineral-bearing quartz-veins, it was suggested, were probably contemporaneous with those which were found to occur in irregular form within the intrusive rock, and which were held to represent the final product of the magma. In these quartz-veins the metallic minerals are chiefly stetefeldtite and some lead, copper and iron.

In the Toyabe range there are numerous ore-deposits, of which the chief ones lie near Austin, about 65 miles north of Belmont. Mr. S. F. Emmons has described many of the deposits, which in nearly every case consist of white quartz-veins carrying metallic sulphides. In the vicinity of Austin the veins are mainly in granite. In other parts of the district, however, the veins occur in the stratified rocks. In some of the veins the chief silver-bearing mineral is a mixed sulphide of antimony, as is the case in the neighborhood of Belmont. There is probably, here, an intimate connection between the metalliferous quartz-veins and intrusive rocks.

About 15 miles east of the eastern edge of the Silver Peak quadrangle is the Southern Klondike district, which I have visited and studied briefly. At this camp the main country-rock is Paleozoic limestone, which is intruded by a long, dike-like mass of siliceous granitic rock, of a composition similar to alaskite. The rock, as a whole, is closely related to that which I described from Belmont, and also to the alaskite of Mineral ridge at Silver peak. Occasionally, there are in the igneous mass small segregated portions of pure quartz, in which bunches of pyrite and, more rarely, galena occur. The limestone near the contact has been altered to hornstone containing epidote, zoisite and other characteristic products of contact-metamorphism. Not many yards from the contact, in the altered limestone, is a quartz-vein which follows parallel to the contact closely for a mile or more, and carries scattered values of silver and gold. The minerals contained are chiefly galena and pyrite, with small bunches of the rich black copper-silver sulphide or stetefeldtite, which has been described as characteristic of those veins in the Silver Peak quadrangle which are near the contact of the intrusive granite, but not in the granite itself.

All these mineral districts are closely similar. All the ores have evidently originated as the result of the intrusion of granitic bodies into Paleozoic sediments, and, in all cases, the ore-

deposition was associated with contact-metamorphism. The granitic and alaskitic rocks which make up these intrusive bodies are similar in those districts which I have examined; namely, Silver Peak, Southern Klondike and Belmont, and from Mr. Emmons' description, in the Toyabe range.[13]

In the three districts which I have examined there are similar peculiarities of the intrusive rocks, notably the segregation of small contemporaneous quartz-masses within the rock, and the alteration of the feldspar to muscovite by magmatic processes.

In the Sierra Nevada, associated with the granitic intrusions, are auriferous quartz-veins, the formation of which immediately succeeded the granitic eruption. The relation between these quartz-veins and the granite has long been noted.[14] Recently, Mr. Lindgren has adopted the hypothesis, that the solutions which deposited the veins were of magmatic origin. These Californian gold-quartz veins are characterized by the common occurrence of albite as a gangue mineral.[15]

VIII. Conclusions Concerning the Silver Peak Type of Ores.

The general conclusion is that the Silver Peak deposits are part of a larger province, which is represented more abundantly in the Sierra Nevada of California, with only outlying smaller areas in adjacent portions in Nevada. All the ore-deposits of this province seem to owe their existence to the intrusion of the post-Jurassic granite. The ores of this province have been concluded to be due to siliceous solutions, which were due to the crystallization of the granitic rocks. These solutions deposited the minerals they contained (silver, gold, etc.) along fractures or shear-zones or other channels, thus forming the typical gold-quartz veins of the region. In Nevada these solutions formed, where the wall-rock consisted of

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[13] *U. S. Geological Explorations of the Fortieth Parallel*, vol. iii., p. 324 (1870).

[14] Whitney, J. D., *The Auriferous Gravels of the Sierra Nevada of California*, p. 353 (1880). Kemp, J. F., *Ore-Deposits of the United States and Canada*, 3d ed., p. 370 (1900). Lindgren, W., Gold-Quartz Veins of Nevada City and Grass Valley, *17th Annual Report*, U. S. Geological Survey, part 2, pp. 175-6 (1896).

[15] *American Journal of Science*, 2d Series, vol. xxviii., p. 249 (1859); and Ransome, F. L., *Mother Lode District Folio, California*, U. S. Geological Survey, p. 8 (1900).

the calcareous strata intruded by the granite, a type of noble silver-gold veins (that is, veins containing a comparatively small proportion of the baser metals) characteristic of this period.

This metallographic province appears to be most typically developed in California, for which reason we may call it the Californian province, while the province characterized by the ores in Neocene lavas is best represented east of the Sierra Nevada in the State of Nevada, and may therefore be called the Nevada province. In western Nevada the Nevada province overlaps upon the Californian province, and along this overlap the ore-deposits belonging to one group are superimposed upon the other. The Nevada province is co-extensive with the appearance of Neocene andesites and rhyolites at the surface, the Californian province with the appearance at the surface of post-Jurassic granitic rocks. Where, as in western Nevada, these granitic rocks and the strata which they intrude are exposed, by erosion, in patches lying in the midst of Tertiary volcanics, we may have veins belonging to the different periods very close together.

IX. Magmatic Origin of Ores of Both Provinces.

According to the previously-expressed conclusions, all the ore-deposits of this rich region of Nevada can be referred to two chief periods of intrusive igneous activity. The various ore-deposits discussed appear to be genetically connected with one or the other of these two great periods. In both cases the mineralization has been ascribed, as the result of close study, to the final processes of rock solidification subsequent to intrusion, the residual solutions and gases resulting from consolidation having been the agents which produced the mineralization. The metals also are, in all cases, considered to have been derived, together with the mineralizing solutions, from the respective magmas. In this whole district, therefore, the effect of the concentrating action of ordinary circulating ground-water does not enter perceptibly into our conclusions, and so far as we yet know it is negligible, except for some minor effects in re-arranging the ores of the oxidized zone.

Kernel-Roasting.

BY HERMAN POOLE, NEW YORK CITY.

(Washington Meeting, May, 1905.)

When finely divided ferrous sulphide, FeS, is roasted at a moderate, carefully-regulated temperature, the iron and sulphur are oxidized, the first products being probably ferrous oxide and sulphurous acid. In the presence of oxygen of the air the ferrous oxide soon becomes ferric oxide, and, in the presence of oxygen and the ferric oxide, the sulphurous acid oxidizes to sulphuric acid. These facts are well known, having been established by Plattner many years ago.

As a further reaction, some of the sulphuric acid parts with a portion of its oxygen to oxidize more ferrous oxide to ferric oxide, and a portion of it escapes uncombined, or else unites with the iron oxides to form sulphates. Ferrous sulphate is usually soon oxidized to ferric sulphate, and if the heat becomes sufficient, this is then decomposed into sulphuric acid and ferric oxide.

As a result of these reactions a mass of more or less pure ferric oxide is formed which is generally made porous by the escaping gases and, if rabbled properly, practically all the sulphur is expelled.

If ferric sulphide or ordinary pyrites, FeS_2, is roasted, a portion of the sulphur sublimes and usually burns to form sulphurous or sulphuric acid, although at times and under favorable conditions, some of the sulphur is driven off uncombined, and can be collected as such. Under ordinary methods of roasting, however, only a small portion escapes combustion.

By the combustion of the sulphur an increase of heat is developed and, as a consequence, the reactions mentioned take place more rapidly and actively,—more sulphuric acid is formed and the oxidation is more complete—nearly all the iron being left as ferric oxide with practically no sulphate or ferrous oxide.

When the iron sulphide is in lumps the roasting proceeds generally as with fines, but with some changes due to mass. The

action of the air on the sulphide is *ab initio* of the same nature and yields the same results, but soon another and modifying influence comes in. The air cannot penetrate the lump as readily, and soon is formed a crust of ferric oxide, more or less porous. The oxidation proceeds more slowly towards the interior, and, in time, penetrates the entire mass, yielding a dark brown or red porous cinder composed almost entirely of ferric oxide, containing only a small percentage of sulphuric acid and a smaller one of unoxidized sulphur.

The action in the interior is not a simple oxidation by air alone, because this action is aided by the sulphuric acid generated and the high temperature.

In case the pyrites contain a small percentage of copper sulphide, an additional phenomenon is noticed. The roasting begins, as before, by oxidizing the iron sulphide, but in a short time there will be found a layer of iron sulphide richer in copper, which is formed under the external layer of ferric oxide and distinct from it. As the roasting proceeds this layer moves towards the central and cooler portion of the lump, and finally a kernel of rich, copper sulphide, approaching matte in composition, is formed at the center. At times, when the roasting is pushed to the limit, a small button of metal is found at the center. The outside layer of ferric oxide usually has a very small percentage of copper—much less than that of the rich layer mentioned or the kernel. The dividing-line between the poor ferric oxide and the enriched sulphide layer is usually well marked, and they can be separated fairly well.

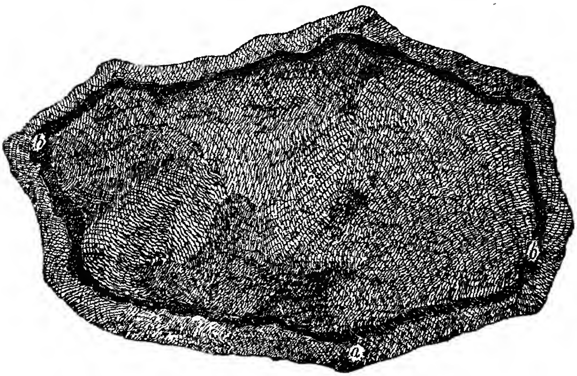
The following sections of cinder show the different stages of roasting.

Fig. 1 (Plattner) represents a section through the lump of pyrites exposed a short time to the roast.

Fig. 2 (Plattner) represents the cinder at a more advanced stage of the roasting.

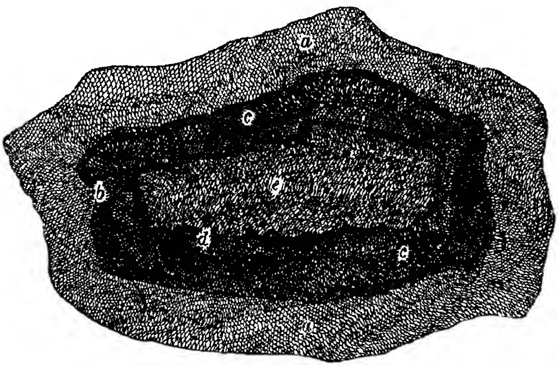
Fig. 3 represents the cinder at a still further and final stage of the roasting.

This property of copper sulphide of concentrating during roasting, if mixed or combined with iron sulphide, has been used as the basis of a metallurgical process at several places. Of late years it has been mostly abandoned as being too long, and not giving as good results as more recent methods. The



a, shows the exterior ferric oxide crust ; *b*, shows the layer of enriched sulphides ; *c*, shows the interior unroasted portion.

FIG. 1.—(From Plattner.) SECTION THROUGH A LUMP OF PYRITIFEROUS ORE, ROASTED FOR A SHORT TIME.



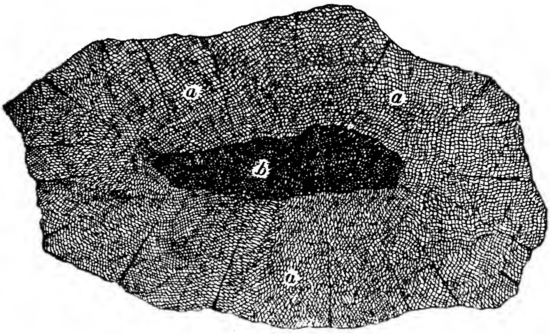
a, shows the crust of ferric oxide ; *b*, shows a layer of enriched sulphides having a composition analogous to bornite ; *c*, shows a layer of enriched sulphides resembling bornite ; *d*, shows a layer of enriched sulphides resembling chalcopyrite ; *e*, shows the comparatively unaltered kernel.

FIG. 2.—(From Plattner.) SECTION THROUGH A LUMP OF PYRITIFEROUS ORE, ROASTED FOR A LONGER TIME.

copper-bearing pyrite was crushed to lumps of about 30 cu. in., and roasted in heaps in such a way that a small distinct kernel was obtained which, after separation from the ferric oxide crust, was smelted for its copper.

Several explanations have been given, all more or less on the same line and all explaining more or less clearly the cause of the action. Still, a doubt has always existed whether the true cause had been fully ascertained, and whether all the reactions supposed to take place in the lump were needed.

The principal writers on the subject are Karsten, Werther, De Lürzer and Plattner. Grüner gives an explanation which was evidently taken from the others. Percy and Peters offer



a, shows the external crust of ferric oxide usually much cracked ; *b*, shows the kernel of enriched sulphides.

FIG. 3.—SECTION THROUGH A LUMP OF PYRITIFEROUS ORE, AT THE FINAL STAGE OF ROASTING.

no explanation of their own. Schnabel gives Plattner's explanation.

Karsten[1] says in substance:

The copper sulphide oxidizes at the same time as the iron sulphide, but the cupric sulphide and the cupric oxide decompose each other at a lower temperature than do ferric sulphide and ferric oxide. The metallic copper, thus freed, removes a portion of the sulphur from the iron pyrites, which thus attains a lower degree of sulphuration.

Werther[2] gives a description of the roasting, as practiced at Agordo, and a free explanation of his translation is as follows:

The proportion of iron sulphide being much greater than that of the copper sulphide and the affinity of oxygen for iron being much greater than for copper,

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[1] *System der Metallurgie*, vol. iii., p. 433.

[2] Tunner, *Jahrbuch des K. K. Montan—Lehranstalt zu Leoben*, vol. iii., p. 339.

the copper remains united with the sulphur while the iron oxidizes. The heat produced by this oxidation fuses the copper sulphide and a portion of the iron sulphide not oxidized. These two sulphides combined infiltrate through the porous crust of oxides and sulphates. In this passage, the iron sulphide gives up its sulphur to the copper oxides which may have been formed. Thus the copper sulphide flows towards the center of the piece. If it is so that the air can reach it from the outside, oxidation will take place and successive reactions will be produced from the outside towards the center. Yet if, for any cause, the sulphide cannot move this, then there will be other smaller nuclei formed in the crust caused by the decomposition of the melted copper sulphide.

He says, further, that proof of this theory is found in the fact that the kernel is rarely found at the center, but usually towards the lower side.

De Lürzer[3] gives a minute description of the Agordo process, and follows it step by step. He had analyses made of the products of the different stages.

In one sample he found the following results:

Central Kernel.	Per Cent	Richest Portion of the Crust	Per Cent
Copper,	41.64	Copper,	3.31
Iron,	28.76	Copper oxide,	1.58
Sulphur,	29.28	Ferrous oxide,	0.10
Gangue,	0.08	Ferric oxide,	85.70
Loss,	0.24	Sulphur,	0.92
	100.00	Sulphuric acid,	2.50
		Gangue,	2.85
		Loss by heating,	3.04

The composition of the enriched kernel approaches $3\ Cu_2S + 4\ FeS$. The samples of the external crust were generally poorer than the above analysis shows, and it is possible a small portion of the kernel may have been broken-off in separating.

He cites the following facts:

1. The affinity of copper for sulphur is stronger than that of iron.
2. Copper sulphide is much more difficult to destroy by heat than is iron sulphide.
3. Under the influence of heat, copper oxide and iron sulphide decompose each other and form copper sulphide. Ferric oxide, on the contrary, has almost no action on copper sulphide.
4. Copper oxide and sulphide react easily, giving off sulphurous acid gas. At times all the copper will be reduced to the metallic state.

His explanation, translated, is as follows:

"At the beginning of the roasting the sulphur contained in the external portion of the lump oxidizes and evolves sulphurous acid. When all the volatiliza-

[3] *Berg- und Huettenmaennische Zeitung*, 1853, p. 139.

ble sulphur of the exterior layer has been given off the subsulphide is oxidized. Oxidation of the iron sulphide is first effected. The copper sulphide, without doubt, loses a portion of its sulphur, but this on account of its great affinity for copper is immediately replaced either from the iron sulphide of the layer under it or by the movement of the attacked copper sulphide towards the interior. In this way he explains the formation of the layer of chalcopyrite in contact with the raw pyrites of the first stage of roasting.

The roasting proceeding, the oxidation penetrates towards the interior and the layer of chalcopyrite is decomposed. The copper sulphide and possibly, also, the copper oxide or even the metal are freed and unite with the copper sulphide of the unattacked portion, abstracting a portion of the sulphur from the iron sulphide. Thus is explained the desulphurizing of the pyrites immediately under the envelope of copper sulphide.

The cuprous envelope continues to move slowly towards the center taking up the particles of copper sulphide and leaving them only when pieces of gangue mechanically oppose the movement, or when the action of the air or heat is irregular. These copper particles thus separated are exposed to oxidation and this oxidation is usually complete, the copper being found as sulphate or oxide.

As the roasting proceeds the movement of transfer is more and more hindered mechanically and in time does not move fast enough to compensate for the oxidation produced on its exterior. Consequently the contained sulphides pass to one of inferior degree. To this cause is due the presence of heterogeneous layers of bornite and chalcopyrite during the second degree of roasting

When the central nucleus is entirely decomposed, the sulphur burnt by exterior oxidation can no longer be restored to the copper sulphide and the exterior portion of this passes to a lower state of sulphuration, the third stage is reached. Finally, in complete roasting, all the kernels of copper sulphide have passed to the state of subsulphide. If we carry the roasting still further, no advantage is gained, as the complete decomposition of the sulphide ensues *The loss in sulphur diminishes the fusibility* (the italics are mine, H. P.) and there are formed several copper-bearing portions mixed mechanically with the oxides.

Plattner[4] says that he thinks the roasting-phenomena may be explained by depending on the following facts:

1. When a combination formed of iron and copper sulphides, in which iron sulphide predominates, is submitted to a low red heat under action of the oxygen of the air the iron sulphide oxidizes before the copper sulphide.

2. When iron sulphide at the maximum of sulphuration, or when the combination of sulphides is mixed with pyrites, that is to say, in the case when the substances submitted to a red heat can evolve vapors of sulphur, the copper is protected from oxidation as long as this evolution of vapor lasts.

3. The oxidation of iron sulphides and the formation of sulphuric acid produces sufficient heat to liquefy the copper sulphide and change the mixture of the sulphides so that they can combine with each other

The heat determines at the surface of the lump the affinity for oxygen and, at the same time, the sublimation of a small quantity of sulphur. Sulphurous acid and ferrous oxide are produced—a portion of the sulphurous acid is trans-

[4] *Rost-prozesse.* This passage has been translated from the French version of Alphonse Fétis, published under the title *Traite Theoretique des Procédés Metallurgiques de Grillage,* Paris, 1860, p. 201.

formed into sulphuric acid by contact with the ferric oxide. Part of the ferrous oxide combines with the sulphuric acid to form ferrous sulphate which changes at the high temperature to ferric sulphate and then to ferric oxide, the acid escaping.

The copper sulphide has been protected from oxidation by the sulphur vapors disengaged in small, but continuous, quantities. Besides owing to the heat generated the sulphide has been heated to fusion and in this state unites with a portion of the original sulphide, the tenor in copper being thereby increased.

The interior air acts as an oxidizer as long as the layer of ferric oxide is thin. It continues to form sulphurous acid and ferrous oxide which, as we have seen, change to sulphuric acid and ferric oxide. As the thickness of the crust augments direct oxidation by the oxygen of the air diminishes, but the action is kept up by the sulphuric acid. In fact, the pores of the crust are filled with vapors of sulphurous acid and sulphur which fix the oxygen of the air before it can reach the sulphide surface.

When the action has continued for some time all the copper originally contained in the sulphides changed to oxide is concentrated. It forms with the unchanged iron sulphide a layer resembling chalcopyrite, $Cu_2S + Fe_2S_3$.

The roasting being continued, only the sulphur of the iron sulphide in the new cupriferous combination is oxidized by the sulphuric acid, the copper sulphide being protected by the sulphur vapor. Concentration continues gradually until a combination approaching bornite, $3\,Cu_2S,Fe_2S_3$, is reached. As long as the temperature of the center is not high enough to sublime the excess of sulphur from the pyrites and the evolution of vapor is not hindered by the pressure in the pores of the crust, the copper sulphide is protected from oxidation. Hence, the composition of the copper sulphide layer becomes richer in copper and approaches that of matte, Cu_2S,FeS. When, finally, the temperature of the center increases the pyrites nucleus loses its sulphur and the result is a various combination of copper and iron sulphides.

When, finally, the operation is carried to the point at which sulphur vapor is no longer evolved, the temperature increasing, the copper tends to diffuse itself uniformly through the mass of iron sulphide Still the oxidation of this latter continues at the expense of the sulphuric acid and even then the copper is not sensibly oxidized.

Roasting being pushed still further cuprous oxide is formed, which reacts with a portion of the cuprous sulphide, is reduced to the metallic state and in presence of only iron sulphide cannot again unite with sulphur.

He refers to the formation of small minor nuclei throughout the mass, and accounts for them on the same general principles as enounced by Dr. Lürzer.

Grüner[5] says that, during roasting, each piece of mineral is composed of a central sulphurated nucleus, sensibly intact and surrounded by an envelope already oxidized. Between the two is found a moderate-sized zone where the roasting proper is going on. The air arrives by the cracked oxidized crust, and there burns the sulphur and the iron. The heat thus produced changes the iron bisulphide, FeS_2, to monosulphide and sulphur,

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[5] *Encyclopédie Chémique*, vol. v., Fascicule II., p. 113.

the evolved sulphur being burnt by the air and the copper oxide of the roasted crust. This copper then forms Cu_2S, which is fusible and very fluid when melted. It may thus easily act on the ferrous sulphide just formed, for which it has an affinity. The union of the two sulphides is favored, besides, by capillary action of the fissures in the central nucleus, which are finer than those of the external crust. Thus, on account of its affinity for sulphur, it moves continuously from the outside towards the center, which is thus found to be enriched. A mineral, having from 3 to 4 per cent. of copper, has given a central kernel of from 15 to 20 per cent. and an external crust containing only 2 per cent. of copper.[6]

If we take iron sulphide or copper sulphide in a fine state of division and add it, with stirring, to melted sulphur heated a little above its melting-point, the sulphides dissolve and form a very thin liquid. Sulphur, as is well known, when heated above its melting-point grows thick, like boiling molasses, and finally gets so thick it cannot be stirred. It then smokes and will easily inflame. But on adding the ground sulphides the mass gradually liquifies as the solids are stirred in. This solution of sulphides in sulphur, if heated still further, gradually assumes the thickened stage, like clear sulphur; and, on cooling, passes through the very liquid condition and then sets, forming long needle-like crystals, all interlocked.

The fumes evolved from this solution carry with them, mechanically or otherwise, some of the sulphides, as is shown by the sublimate collected being dark colored and leaving an oxide residue on ignition. Some other sulphides act similarly, but not to so marked a degree. Silver sulphide and lead sulphide are dissolved with comparative ease, but zinc sulphide only slightly.

It is admitted:

1. That sulphur possesses a stronger attraction for copper than for iron.

2. That oxygen possesses a stronger attraction for iron than for copper.

3. That iron sulphide, FeS_2, decomposes on heating, giving-off one molecule of sulphur in the free state.

It seems to me that in the above-mentioned facts we have

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6 [illegible]

enough on which to base a solution of the problem. There is no need of imagining any mysterious transformations and re-arranging of molecules going on in the mass. These may take place, and it would be a difficult task to disprove or prove it, but I do not deem the assumption necessary.

On being submitted to the roasting temperature and conditions, the pyrite, FeS_2, is first decomposed, giving off some of its sulphur. It is then oxidized to either ferrous or ferric oxide, and later becomes all ferric oxide. A small portion of the copper sulphide may be oxidized, but the bulk of it will resist oxidation under the protecting influence of the sulphur vapor and the stronger affinity of the large proportion of iron sulphide. A portion of the sulphur vapor escapes and becomes oxidized to sulphurous and sulphuric acid, and another portion becomes cooled by the cooler internal portion of the lump, and dissolves some of the copper and iron sulphides. This solution then penetrates the porous crust until it meets the internal portion, which is cool enough to hold it solid, or nearly so. Any part of this solution which may become sublimed would naturally be drawn towards the cooled internal portion and become fixed there. A small part of it would, of course, reach the zone of oxidation and become united with oxygen. The vapor of sulphur, passing over the heated unoxidized copper sulphide, would have a tendency to dissolve it, and possibly by so doing have its temperature lowered sufficiently to become liquid.

It is easy to see, then, during the first stage, how a layer of the compound, high in sulphur and copper, could be formed just inside the crust of ferric oxide. During the second stage this layer would be acted on by the oxygen and heat and would be re-liquefied and driven in, part being decomposed and new material added from the sulphides underneath. Still later, when nearly all the original iron sulphide had been oxidized, this would be attacked, and by virtue of the affinity of iron for oxygen and copper for sulphur, the iron would oxidize first and the copper become still more concentrated.

The other attendant phenomena, such as the formation of metallic copper at the kernel in the complete roasting, the presence of smaller nuclei through the mass of ferric oxide, etc., have been explained by others, or are easily explained by the above theory. These phenomena need not be recounted here, because they have no direct bearing on the theory proposed.

Biographical Notice of Sir Lowthian Bell, Baronet.

BY PROF. HENRY M. HOWE, LL D., COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK.

(Washington Meeting, May, 1905.)

THE death of Sir Lowthian Bell removes almost the last of the group of heroic leaders who made their age and ours the Age of Steel—a group which his luster and the luster of his peers, Bessemer, Siemens and Tunner, made one of the most brilliant, perhaps even the most brilliant, in the annals of industry.

Born on February 15th, 1816, in Newcastle-on-Tyne, he was the eldest son of Thomas Bell, an alderman of Newcastle, and of his wife Catherine Lowthian of Newbiggin, near Carlisle, in Cumberland, and was christened Isaac Lowthian, the name of his maternal grandfather. His father was born about 1788, and came in 1808 from Newbiggin to Newcastle, where he entered the office of the Cumbrian firm of Losh & Company, manufacturers of alkali and wrought-iron, at the Walker Iron and Alkali Works, at Walker, near Newcastle.

Young Isaac Lowthian Bell was educated at Dr. Bruce's school in Newcastle, whence he went to Germany and Denmark, learning there German and Danish. On his return he studied at Edinburgh University, and then at the Sorbonne in Paris. As a student he already showed the remarkable character and application which later gained him such distinction. After studying the manufacture of alkali near Marseilles, he returned, and when about twenty years old (A.D. 1836) was employed in his father's firm, then called Losh, Wilson, & Bell. After spending a year in their Newcastle offices, and after visiting the important iron-making districts of France, Germany, Poland, and Austria, he took charge of their rolling-mills at Walker, and profited so well by his opportunities, and especially by the teachings of his father and of Mr. John Vaughan (later one of the founders of the great firm of Bolckow, Vaughan & Co.), that he was made manager of the Walker works in or about

1840, and, on his father's death in 1845, the managing partner, a position which he held until 1850.

Meanwhile, in June, 1842, he had married Margaret Pattinson, the beautiful daughter of a romantic marriage. Her parents, Hugh Lee Pattinson, F.R.S., the eminent metallurgical chemist, and Phœbe Watson his beautiful wife, were both born on the last Christmas day of the last century but one, and on their nineteenth birthday they ran away from their homes at Alston and were married at Gretna Green.

Sir Lowthian had six children, Thomas Hugh, Florence (Mrs. Walter Johnson), Mary (Baroness Stanley of Alderley), Ada (the wife of Colonel Godman—a rare and exquisite woman who died in 1900), Charles Lowthian, and a daughter who died in infancy. His eldest son, now Sir Hugh Bell, Baronet, has twice been mayor of Middlesbrough, and with his brother Charles and his brother-in-law, Mr. Johnson, has long been actively engaged in directing the affairs of Bell Brothers. Sir Hugh's son, in turn, Captain Maurice L. Bell, fought in the late South African war. Sir Lowthian's younger son, Colonel Charles Bell, who was born in 1855, also has been mayor of Middlesbrough, and was for many years commander of the First North Yorkshire Royal Artillery Volunteers.

A goodly array of grandchildren and even great grandchildren promise to perpetuate *in secula seculorum* the stock of the illustrious metallurgist.

In 1844, after the birth of their first child, the Bells moved to Benton near Newcastle, moving in 1854 to Washington Hall which he had built, and in 1874 to his new and stately home Rounton Grange, about seventeen miles from Middlesbrough, in a most beautiful country. This was henceforth his chief residence, though in his last years he would stay for months at a time at the home which, as a delight of his extreme old age, he ingeniously contrived within the Carthusian monastery of Mount Grace. Of this more anon. It was at Rounton that he passed away, peacefully and with resignation, on the morning of December 20th, 1904.

That, when he married, Bell had already begun his remarkable activity, is shown by the work which he was then doing. In that same year, 1842, he built at Walker the first blast-furnace ever specially intended for smelting the Cleveland iron-stone.

In 1844, with his brothers Thomas and John, he formed the firm of Bell Brothers, and leased blast-furnaces at Wylam-on-Tyne; and in 1849 he designed the chemical works, founded by himself, his father-in-law and Mr. R. P. Bowman, at Washington, eight miles from Newcastle, and there made alkali, oxychloride of lead, and the first British aluminium. Thus he was the head and active spirit of three important establishments at the same time. In 1850, however, he retired from the Walker firm.

In this year came the discovery, by Mr. John Vaughan, of the great deposit of Cleveland iron-stone, the most important step in the creation of the gigantic Cleveland iron industry. With the burden of his new and difficult chemical manufacture at Washington still heavy on his shoulders, Mr. Bell and his brothers quickly entered the new industry, established the Clarence works on the Tees opposite Middlesbrough, the center of the Cleveland district, in 1852, at the time when the first Cleveland furnaces were building, and blew-in four furnaces in 1854.

During the half-century between the starting of these works and his death he directed them and the Washington works—in his later years as chairman of the board of directors—with such skill and wisdom, that, from making 12,000 tons in their first year and about 24,000 tons in their fourth, they have now come to making yearly about 350,000 tons of pig-iron and nearly 100,000 tons of basic open-hearth steel, to mining and quarrying about 665,000 tons of coal, 1,177,000 tons of ore, and 236,000 tons of limestone, and to employing between 5,000 and 6,000 workmen. In considering the pig-iron product of this company, which indeed may be looked on as almost a family enterprise, we should remember that to make 350,000 tons of pig-iron needs nearly twice as much of the poor ores of Middlesbrough as of the rich ores of Lake Superior which the Pittsburg smelter uses.

In that half-century the Clarence works enlarged their furnances from the original height of about 50 ft. and width of about 16 ft. to a height of 80 ft. and a width of 20 ft., and replaced the original four with twelve; were the first to work the great salt-bed underlying Middlesbrough; built by-product coke-ovens; established with great success a $1,500,000 basic

open-hearth plant for making steel from the very impure Cleveland ores; built in connection with this the first European regeneratively-heated mixer, using it also for partly fining the pig-iron; used among the very first the Saniter desulphurizing process, though later developing another way of desulphurizing better suited to their conditions; probably made the first regular and successful use, outside of Russia, of slagging-off in the open-hearth process; allied themselves with the important firm of Dorman, Long & Co., and made in a single year a profit of $1,800,000.

In 1873 the firm of Bell Brothers became a limited liability company, the shares of which, at the time of Mr. John Bell's death in 1888, were owned almost wholly and nearly equally by that gentleman and Sir Lowthian, though the children of the latter owned a relatively small part. A few years later Sir Lowthian bought all of his late brother's share. In 1899, seeing clearly the advantages of a grander scale of work, Bell Brothers offered to the public $2,000,000 of preferred stock and $2,000,000 of debenture bonds, which were subscribed for many times over.

Sir Lowthian's exploitation of the great salt-bed was characteristic. About 1864, Bolckow, Vaughan & Co., in sinking for water, found a bed of salt 100 ft. thick. Several years later they attempted to reach it by means of a shaft, but they were prevented by the great quantity of water which they met. From his study of the local geology Sir Lowthian believed, and in 1880 proved by boreholes, that this bed underlay the Clarence works also, which lie on the opposite side of the Tees from the works of Bolckow, Vaughan and Co. By adopting a Continental method he avoided the difficulties which had balked his neighbors. He sank a 16-in. pipe, perforated with many holes where it passed through the great salt-bed, set inside this first pipe a second, open at the bottom, poured water into the annulus between them, and in June, 1882, pumped up this water, now rich in salt, through the inner pipe. Since then the work has been carried on regularly, and others have copied him, until now more than 200,000 tons of salt are made on the Tees yearly.

To the public service he gave his time freely, although his directness and reserve almost forbade him to expect those re-

wards which are selfishly to be expected from politics. On January 4, 1850, while he carried the heavy load of directing the newly built Washington works, and of designing and building the Clarence works, he entered the Council of Newcastle, and, with some brief intervals, he served in it for nearly thirty years. He was elected Sheriff on November 9th, 1851, Mayor on November 9th, 1854, and again on November 9th, 1862, this time to preside over the festivities connected with the marriage of the Prince of Wales and the expected coming of the British Association to Newcastle, which naturally wished to "put its best foot foremost." In preparing, as Mayor, a report on a case of shipwreck, he urged the importance of fixing rigidly by legislation the proper load-line for vessels, and so was a pioneer in the important movement successfully championed later by Mr. Plimsoll. In 1885 he was appointed High Sheriff of Durham county, a position of great honor.

A strong Liberal, he was twice elected to Parliament in 1876, for North Durham and for Hartlepool. His first election and that of his colleague were invalidated on account of intimidation by their agents, for which no blame attached to the principals. On his second election he served until 1880. The great split which then came in the Liberal party disinclined him to further political life; for, though truly a Liberal in that he was for well-guided progress in all directions, he could not bring himself to follow Mr. Gladstone in his Home Rule policy for Ireland.

The Iron and Steel Institute was brought into being in large part directly through his initiative and effort, and indirectly through the liberal spirit with which he inspired his fellow iron-masters. Taking a most active part in its work from its birth till his death, he stamped his character on it more deeply, I think, than any other man. It was in some sort an outgrowth of the meetings which, in 1868, took place for purely commercial reasons between the ironmasters of Newcastle and of Middlesbrough. Their secretary, Mr. John Jones, in his paper on "The Position of the Iron Trade in Relation to Technical Information," read at their meeting on September 29th, 1868, proposed that they should consider scientific as well as trade matters. To quote Sir Lowthian, "Thereupon I was requested to read a short address on the subject at Newcastle. This was

followed by a few friends meeting at my house, of whom Mr. William Whitwell and myself are the sole survivors. Such was the origin of the Iron and Steel Institute." Next followed a meeting of ironmasters called at the Queen's Hotel, Birmingham, on October 8th, 1868, the day of the quarterly meeting of ironmasters there. Mr. Bell here offered a resolution, which was adopted, calling for the formation of the Institute.

It was characteristic of his breadth that he wished this new body to represent the iron industry not only of Great Britain but of the world; and of his skill that, fearing reasonably that the ancient and powerful Welsh iron-trade would resent being led by what it regarded as the mushroom iron-trade of the north, the Duke of Devonshire was put into the field as the first president of the Institute, an irresistible magnet and magnate, himself deeply interested in iron-manufacture, and like the present duke a life-long friend of Bell's. He was followed by Bessemer and then by Bell himself, who during his presidency received the first of the Bessemer gold medals.

Throughout the rest of his life Bell took a most active and ardent interest in the Institute; wrote for it twenty-six papers, or nearly twice as many as any other writer, on a great variety of subjects; and, until within a very few weeks of his death, as a member of its publication committee, scrutinized with great care every paper offered to it, though in his last years his failing eyesight made this work extremely laborious.

It was the Iron and Steel Institute that had the privilege of publishing Bell's greatest work, *The Chemical Phenomena of Iron Smelting;* for, marked as was his success as an ironmaster, it is this astonishing work that gives him his chief claim to great preëminence among metallurgists. We may indeed ask ourselves whether this is not by far the most wonderful of all works on metallurgy. The economies caused by lengthening the Cleveland blast-furnaces, and by heating the blast, had led to the expectation that, by going farther in these directions, the fuel-consumption might be further lessened by nearly half, or from 22.5 to 13 hundred weight of coke per ton of iron made from Cleveland ore. The importance of this question led Bell to make a most remarkable series of investigations into the nature of the reactions of the blast-furnace. These he carried out with the skillful aid of the late Dr. C. R. Alder-Wright,

publishing their results, when he was 55 years old, in 1871, in the first three volumes of the *Journal of the Iron and Steel Institute*, and in 1872 in book form.

Translated quickly into French, German and Swedish, this work, which had found the blast-furnace process empirical, obscure, uncomprehended and apparently inscrutable, indeed the most incomprehensible as it was the most important of all metallurgical processes, made it at a stroke scientific and clear. The revolution, though different in type from Bessemer's, was of the same general order of merit, if we consider difficulty, skill and tactics. Bessemer, a man of titanic force and wonderful mechanical ingenuity, forced a dramatic revolution upon steelmaking: Bell, a profound thinker, through persuasion revolutionized as completely our attitude towards iron-making. Bessemer probably owed much of his fearlessness, and hence of his success, to his initial ignorance of the art he invaded; by his sheer force and his British unconsciousness of defeat he persevered through costly and even disastrous experiment upon experiment; Bell, profoundly versed in his art, achieved his victory through thought rather than through reverses, by searching cross-examinations of nature in the laboratory, rather than by pitched battle. Bessemer was as Cœur de Lion cleaving an iron bar with a sword-stroke; Bell as Saladin severing a silken cushion with a turn of his scimeter.

Continuing at Clarence his blast-furnace experiments, and accumulating in his extensive travels and through correspondence an immense store of information concerning both the scientific and the commercial sides of iron- and steel-making, he published in 1884 his *Principles of the Manufacture of Iron and Steel*, marshaling in order this great array, and presenting anew and in more accessible form the general results of his earlier classical work.

Bell Brothers and the Iron and Steel Institute were by no means alone in receiving to the very end his close attention and active aid, for these he gave generously in many other directions: to the education, housing and general welfare of his workmen and tenants; to the Newcastle College of Physical Science; to Dame Margaret's Home for Waifs and the schools connected with it, in his old home, Washington Hall, which he gave in memory of his wife for this worthy charity; to mediæ-

val architecture, which he served by restoring the great Carthusian monastery of Mount Grace, replacing in one part of it the very furniture and vestments, and converting another part into a comfortable, well-heated, modern residence, which yet preserved the quaint form and flavor of its own early days; to our own society by important papers, and by generous encouragement and endless kindness to its members, to more than one of whom he caused a high honor to come; to the North-Eastern railway, which he, the oldest railroad director in the kingdom, long served as vice-chairman, making for it even in his last years most laborious investigations.

Thus, in 1896, when he was already 80 years old, and again in 1900 when he had reached the age of 84, he presented to it two most remarkable printed reports, the former of 84, the latter of 147 pages, on the *Wear of Rails and Broken Rails.* In these he discussed in his usual broad and deep-seeing way the questions of wear and of rupture, in the light of his vast accumulation of data, and of his observations, by means of special autographic apparatus which he designed, of the deflections both vertical and lateral of rails under passing wheel-loads. If, in accordance with his wishes, this great mass of information is hereafter supplemented by the North-Eastern Company with certain further data, it will furnish a mine ready and opened for stoping, from which extremely valuable laws may be won. In doing this most laborious work, not only at a great age but when his very great difficulty in seeing raised an obstacle which to most men would seem absolutely insurmountable, he, like those titans, the blind Milton and the deaf Beethoven, taught the cravens who seek excuse from labor in any physical defect or suffering, that the senses are but tools of the mind, invaluable but not indispensable.

Whatever he touched seemed to draw from him his breadth and spirit of progress—not less Bell Brothers and the Iron and Steel Institute than the North-Eastern railway, which was the first in Great Britain to use electricity as a motive power.

So varied were his interests, that, even when I last saw him within a few months of his death, board-meetings and trips to Newcastle, York, and London still seemed always in order.

With deep sympathy for his workmen, he led to the early breaking of the general strike of the Durham County coal-

miners in 1879 by proposing arbitration to his own men. That they appreciated his sympathy and justice was shown by their giving him, on March 25th, 1850, a handsome candelabrum on his retiring from charge of the Walker works; on February 22d, 1881, an illuminated address, recording their appreciation of his constant kindness and consideration towards his Roman Catholic employees, though he was a devout Anglican; in June, 1894, a congratulatory address on the semi-centennial of the Clarence works; and at all times their loyal services and profound respect.

Though he took up literary work rather late, at the age of 47, and though writing was always a heavy labor to him, because he forged each sentence with care, and thought out every paragraph conscientiously, he wrote voluminously, as is shown by the list given in London *Engineering* (Dec. 23, 1904, vol. xxviii., p. 863) of about fifty of his papers and addresses published in England. Of these many were reprinted on the Continent in other languages.

To the *Transactions* of this Institute he made five valuable contributions, namely:—

Title.	Volume.	Page.	Year
Remarks on Coal-Washing in England, . .	iii.	182	1874
On the Hot Blast, with an Explanation of its Mode of Action, etc., ...	v.	56	1876
The Probable Future of the Manufacture of Iron, .	xix.	834	1890
Remarks on the Wear of Rails, ...	xix.	909	1890
Remarks on American Blast-Furnace Practice, .	xix.	957	1890

After the two momentous books already described, his papers on the removal of phosphorus and the other elements from iron, in the *Journal of the Iron and Steel Institute* for 1877, are probably his most important writings, for in these he outlined his "purifying process" for dephosphorizing iron without removing its carbon, and thus was the first to solve the then pressing problem of dephosphorizing. This process, usually called the "pig-washing" process, or the "Bell-Krupp" process, from its having been invented almost simultaneously by Bell and Krupp of Essen, though Bell anticipated Krupp in describing it, is still in use at Youngstown, Ohio, in the skillful hands of Mr. E. W. Ford, and also at Steelton, Pennsylvania, under Mr. H. H. Campbell, for making "washed metal," i.e., dephosphorized and desilicidized cast-iron, for use as the raw

material of the crucible-steel process. Probably it would have been generally adopted as a means of preparing phosphoric pig-iron for the acid open-hearth process, and would thus have led to a great development of this latter process, had not Thomas in the following year, at the meeting of the Iron and Steel Institute in connection with the Paris Exhibition of 1878, offered, in the shape of the basic Bessemer process, a still better solution of the problem of dephosphorizing. It was characteristic of Bell's manliness that he never suggested how much Thomas might have been indebted to his experiments described so fully in 1877.

Honors come unsought to such a man, greatest honor of all,—the love of his countrymen and the esteem of the world. Of the formal honors probably the earliest was his honorary membership in the American Institute of Mining Engineers, to which he was unanimously elected on May 21st, 1872, the second of the eminent men who have received this distinction. He was the first Bessemer medallist; a Fellow of the Royal Society; a non-resident Fellow of the American Philosophical Society and of the Société d'Encouragement pour l'Industrie Nationale (the title in both cases in fact corresponds to honorary membership); an officer of the Legion of Honor of France; a Fellow of the Academy of Sciences of Sweden; and holder of the honorary degrees of D.C.L. (Durham), D.Sc. (Leeds), and LL.D. (both Edinburgh and Dublin). In 1885 he was made a baronet by Queen Victoria.

Never physically robust, and as a boy not equal to his fellows in the mild athletics and sports of those days, with his health and even his life more than once very seriously threatened, he yet had wonderful power of doing and making others do, as what I have already said abundantly shows. True and unselfish friend, with a warm and youthful heart under a surface of reserve; careful father and head of family; faithful and laborious public servant; philanthropist; well- and broadly-read scholar; convincing controversialist; pioneer and great general of industry, reaping its material fruits abundantly for himself and others; inventor; illustrious technical and economical writer; brilliant scientific investigator;—he seemed to belie the old saying that one may not go far into many lanes. What was his secret? In my opinion, it was unswervingly following

a path which is open to thousands and tens of thousands of us. You cannot find it in his strength, for that as it came to him was certainly not unusual; not in his intelligence, for excellent as that was, it was of no extraordinary or transcendent kind; not in an overmastering will, for strong as that was, he was ever considerate of others and never so selfish as to impose his will unless he saw clearly that it was for the best; not in his opportunities, for good as these were, they were open simultaneously to thousands of others who did not profit by them, and indeed as good opportunities are open every day to him who will seize them. His secret was no secret; it was consistent and persistent devotion to duty, regulating his life, his mind, his very thoughts so as to accomplish the greatest possible result with the gifts of good judgment, good intelligence, good opportunities, good health and a good heart. These gifts are not rare; it is his use of them that is rare. It is not enough that we control our appetites, that we are abstemious; we must indeed control our bodies, but we must also control our minds. His own version was, "plain living and plenty to do." But this was not all. He was as temperate in his work and in his judgment as in his fare. Was his head tired? He took nature's hint and rested the tired brain as he would rest a tired muscle. With that brain he must do a life's work; he treated it so as to do the utmost with it, not in a day, a year or a decade, but in a lifetime. The incipient fatigue over, he returned to his task again and again, with unshakable pertinacity, until he had mastered it completely, until the whole situation was clear before him with all its possibilities and dangers. Was information lacking? Let it be supplied. Wait till you master the situation; wait if necessary for all needed information; devise, if need be, means for getting that information; learn what others in other countries and continents can tell you. But when your mastery is complete and one course stands before you as the wisest, take it and hold to it steadfastly: not blindly, ignoring the changes which new events commend to you, but steadfastly, with the ground of your original decision clear in your mind. Calm and deliberate in judgment, prompt in action, he was called prescient; but, unless prescience is something supernatural, it must be a phenomenon or result of common and natural qualities. He was indeed prescient; and to this pre-

science, this courage to strike out a new path, much of his achievement was due; but it was no separate gift; it was the natural result of his habit of mind. He saw ahead because he looked steadfastly ahead. He saw the future because he studied the facts, the possibilities, patiently, temperately, with careful husbanding of his powers.

Temperate in fare and in work, he was temperate in sentiment, firmly avoiding nerve-exhausting and judgment-warping resentment, jealousy, envy, hatred, malice and all uncharitableness. He was calm, deliberate, and thereby just in his judgments. I never knew him to say an uncharitable word, or to give sign of an uncharitable thought. Here again came out his self-control, his persistent devotion to his life's work, his guard against the waste or misdirection of his powers.

The calm student of life's work sees that if we are to take we must give; if we are to reap we must sow; as we judge so shall we be judged; as we treat so shall we be treated. His charitableness, his generosity of judgment and of purse, his free giving of knowledge and of affection sprang, as they normally must, from the heart; but their rule was more complete because the clear and patient head saw that they made for the fuller and better accomplishment of the tasks which his Creator had set before him.

Here, then, is the lesson of his life: that with gifts not in themselves marvellous he accomplished marvellous results, reaping extraordinary benefits for himself, his country, and his race by means open to us all, by patient, temperate, truth-seeking, reasoning, pertinacious study of every problem, by devoted prosecution of his work, by bodily, mental and emotional temperateness, by charity, generosity, and kindness. It is the old, old story, the transcendent value of character.

Present Problems in the Training of Mining Engineers.*

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"THE man is always greater than his work." The training of the men who are to develop the mineral resources of the world is the most important problem connected with mining engineering. It becomes ever more important to civilization as the mineral wealth of the earth approaches exhaustion. I have therefore decided to consider a few of the more important problems arising in the training of the mining engineer, and especially those arising in America.

THE PECULIAR NATURE OF MINERAL WEALTH.

Mining and Agriculture are the two fundamental arts. Without the latter our existence would be precarious; without the former, our civilization impossible. Agriculture furnishes that regular supply of food and raiment which leads to the growth of large communities in which cultivated leisure first becomes possible; while mining furnishes the metallic thread from which is woven that complex fabric we call civilization.

But in these two arts the conditions for success are widely different. Most of the crops that the farmer reaps may be harvested year after year, and the proper fertilizers being added, he may continue the annual harvest indefinitely, while, as a result of cultivation, his farm becomes yearly more valuable.

But the crop the miner reaps can be harvested but once in the history of the race. Our mineral wealth has taken unknown ages to mature in the bosom of the earth. The ripened fruit can be plucked but once. There are no fertilizers for worked-out mines. It never pays to work over a mine that has been

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"robbed," either through ignorance or lack of skill; and a worked-out mine is utterly worthless.

These differences between the two kinds of natural wealth have been long recognized, and have led, in the old world, to a very conservative policy in the utilization of mineral wealth.

Though the fragmentary history of primitive mining-law is full of contradictions, it would seem that the development of the mineral wealth of the world was at first everywhere due to the free initiative of the miner, whose exertions were stimulated by the right to possess what his energies discovered. But everywhere in the old world the mailed hand of the sovereign soon seized this important source of wealth and power. It was used at first exclusively for his own benefit, but as more enlightened views of the duty of the sovereign to his people spread through Europe at the end of the middle ages, these special rights and privileges have been used more and more for the benefit of the whole people. At the present time in some of the continental countries, individual initiative and ownership has asserted itself once more; still, it is generally true that, in most of the countries of continental Europe, the mines are either owned or are worked under the direction of the government. In these matters the policy of Great Britain and her colonies has been, in general, intermediate between that of the United States and that of continental Europe. Hence, in what follows I shall dwell chiefly on the differences between Continental and American customs.

Continental and American Mining-Schools.

When European mining-schools were first organized they also came naturally under government control, and there consequently resulted a close union between the mines and the mining-schools. This, in turn, led to many other important consequences. A regular career was opened for the graduates of the mining-schools either by their direct employment in mines operated by the government, or in the inspection and direction of the working of mines under government control. As a consequence of this policy, well-trained men have always had the management of the mines under a sort of civil service system. And also a wise conservation of the mineral wealth of these countries has resulted; the mines are worked syste-

matically, and have often kept producing a steady output for several hundred years, while in our country they would have been worked out and abandoned in one or two decades. While, according to our ideas, there are drawbacks to the Continental policy, it certainly lends a restraining influence to the natural uncertainties of mining life; it gives a more certain tenure of office to the mining officials; and, consequently, results in a more conservative policy in the management. It effects a more complete extraction of all the ore in the deposit, a better avoidance of wastes and a more complete utilization of all the side-products. On the whole, the system, when wisely administered, leads to excellent results.

Its effects on the early development of the mining-schools were also favorable. The close relation between the mines and the mining-schools made it easy for the one to assist the other. The graduates of the mining-schools were as sure of employment in an honorable profession as are the graduates from our government military and naval academies at West Point and Annapolis. Historically, this connection has lent the air of distinction that clings to the profession of the mining engineer, apart from his function as a mere money-getter.

On the Continent two grades of mining-schools have grown up. The *Bergschule* and the *Bergakademie*. The *Bergschule* trains working-miners for the duties of mine foremen, while the *Bergakademie* trains young men of the educated class for the duties of the mining engineer.

The system here outlined possesses many advantages and is admirably adapted to the countries where it originated. But it would be impossible in America. In the first place our government gives away its mines and does not attempt to control either them or the mining-schools. No official connection either exists or is possible between them. Moreover, though there is much to be said in its favor, the sharp distinction drawn between the *Bergschule* and the *Bergakademie* in Europe is at variance with American ideals of democracy.

It has become an axiom with us that not only genius, but also talent, ability and capacity of any kind, are too precious to the entire community to allow them to go to waste. We err, indeed, by going to the other extreme. But there is no doubt that the wonderful industrial progress of America is

largely due to that equality of opportunity that is here practically open to every young man of ability.

The American Temperament.

It has often been claimed that the American temperament is due to our peculiar climatic conditions. As a matter of fact nearly all the climates of the globe characterize our country. And in order to disprove this theory one has only to cross the narrow line that bounds our country either to the north or to the south to find a relief from the strenuosity of the American temperament. The American temperament is due, not to climatic conditions, but to a mental attitude toward life. When a man feels that his future depends, not so much upon his own efforts, but mainly upon the position to which he was born, he is, if not contented with his lot, at least more likely to be reconciled to it; for he feels it idle to waste himself in useless effort. But, if you can convince such a man that there is no limit to his ambition except that of his own powers, you have fired him with the most powerful stimulant that can influence human nature. It is this stimulant, working day and night for over a century upon men descended from every race in Europe, that has produced the American temperament.

It is a temperament that was not unknown in Greece in its great democratic days. Republican Rome felt it, too. But in monarchies its influence is mostly confined to the army and the navy. For in war-times the best man must be had regardless of his birth. Napoleon overran Europe by declaring to his men: "Every soldier carries the Marshall's baton in his knapsack."

The Rôle of "The Practical Miner" in America.

Nowhere in America has this influence been more keenly felt than in the mining-industry, particularly in the Western States. The policy of our government in throwing open to the hardy prospector its ownership in the mineral wealth of these States has stimulated men without previous technical education and training to accomplish what in older countries would be regarded as physical impossibilities.

It is true that the path has been marked with waste of money, labor and life. Blunders, failures there have been, and still

are, innumerable. But the accomplishment is all the more remarkable when we recognize these facts, for it testifies to the almost superhuman energy with which these obstacles have been overcome.

We are greatly indebted to the old world for its contributions to the mining and metallurgic art, but we are beginning to repay the loan with generous interest. And, to tell the truth, it is largely due to the plain average American, without college education or training, that many of these advances have been made. Every one who has mixed much with American miners has met and honored many such uncrowned kings. *And unless the graduate of American mining-schools is ready and willing to meet with this kind of competition without fear or favor, he will surely and deservedly fail.*

This was the first great problem that confronted the American mining-schools, and it has proved their greatest advantage. There is no royal road for their graduates. They cannot depend on the government for places in the mines, because the government neither owns, works, nor attempts to control the mines. Neither can they look to their diplomas as a guarantee of employment.

The American attitude on this question has hitherto been very different from the European. Credentials, degrees, diplomas and recommendations that in Europe carry great weight, in America often receive but scant attention. The American often amuses himself with titles, but deep down in his nature is an instinctive distrust of anyone who takes them seriously. Among the men who have done most to develop the mineral wealth of our country this feeling is particularly strong. What a man is, is more important to them than, who he is. What a man knows interests them but little; it concerns them much more, what use he can make of this knowledge.

Herbert Spencer, a radical in so many of his opinions, was quite in sympathy with this point of view. I quote from his *Autobiography*, vol. i., p. 199, beginning with a passage from a letter to Herbert Spencer from his father.

"'I am glad you find your inventive powers are beginning to develop themselves. Indulge a grateful feeling for it. Recollect, also, the never-ceasing pains taken with you on that point in early life.'" Herbert Spencer then adds:

"The last sentence is quoted not only in justice to my father, but also as conveying a lesson to educators. Though the results which drew forth his remark were in the main due to that activity of the constructive imagination which I inherited from him, yet his discipline during my boyhood and youth doubtless served to increase it. Culture of the humdrum sort, given by those who ordinarily pass for teachers would have left the faculty undeveloped."

Footnote by Mr. Spencer. "Let me name a significant fact, published while the proof of this paper is under correction. In *The Speaker* for April 9, 1892, Mr. Poulteney Bigelow gives an account of an interview with Mr. Edison, the celebrated American inventor. Here are some quotations from it: To my question as to where he found the best young men to train as his assistants, he answered emphatically: 'The college-bred ones are not worth a —— ! I don't know why, but they don't seem able to begin at the beginning and give their whole heart to the work.' Mr. Edison did not conceal his contempt for the college training of the present day in so far as it failed to make boys practical and fit to earn their living. With this opinion may be joined two startling facts; the one that Mr. Edison, probably the most remarkable inventor who ever lived, is himself a self-trained man; and the other that Sir Benjamin Baker, the designer and constructor of the Forth Bridge, the grandest and most original bridge in the world, received no regular engineering education."

Mr. Spencer might have added himself to this list of remarkable self-made men, for his schooling, though excellent as far as it went, was very meager, and he made himself what he came to be.

In the words: "*I don't know why, but they don't seem able to begin at the beginning and give their whole heart to the work,*" Mr. Edison has put his finger with singular acuteness on the principal failing of improperly-trained college students. The reason why they are not willing "to begin at the beginning and give their whole heart to the work" is because their education has often been so exclusively theoretical that they are filled with the conceit of learning, and they have an inordinate idea of their untried abilities. Hence their unwillingness "to begin at the beginning." They feel that they ought to begin at the end and be put in charge of everything. If, in their training, theory and practice had gone hand in hand, this conceit, which is natural to all young men, would have been soon dissipated by the hard realities of practice, and the young men would have been more willing "to begin at the beginning," and more ready and able "to give their whole heart to the work."

At the same time I cannot help thinking that Mr. Edison must have been unfortunate in his choice of "college-bred assistants," or in the colleges that trained them; for, in opposition to his experience, may be quoted the practice of a large number of his important rivals in the electrical business, and of an increasing number of iron and steel, railway, bridge construction and mining and smelting companies, to draw upon the graduates of engineering schools for their assistants; and, where they wisely insist on the men beginning at the bottom and working their way up according to merit, the results have been, on the whole, more and more satisfactory as the engineering schools have adjusted themselves more closely to their environment. I have given these strong statements of the failings of college-bred men, not to endorse them, but because they contain an important truth that must be recognized and met.

This condition of public opinion has from the very first forced the American mining-schools to stand on their own merits. Whatever success they have achieved has been due to this hard necessity.[1] The atmosphere surrounding European mining-schools is so different from that in America, that graduates from such schools have always found in America much

[1] I append in this connection the following concise and caustic note from the *Engineering and Mining Journal*, p. 403, June 12, 1880, which shows the condition of affairs in America only 25 years ago. The hope expressed in the last paragraph has since been largely realized to the benefit of all concerned.

"A correspondent writes us, asking 'If it is absolutely necessary to be a graduate of a school of mines before being able to engage in the business of a mining engineer.' Certainly not; in fact, before engaging in the business of mining engineering it does not appear to be absolutely necessary that a man should know anything at all, as our correspondent can very well satisfy himself by visiting nine out of ten of the mines nearest to him, wherever he may be. Had our correspondent asked, whether it would be desirable that a man should be a graduate of a school of mines before engaging in mining engineering, we should have answered in the affirmative, for the simple reason that the course of study in a school of mines is calculated to give the elementary education necessary for a mining engineer, and, other things being equal, should give its recipient an advantage over those who have learned the business only in practice. The course of study in a school of mines is not, however, sufficient to qualify a mining engineer to take charge of important works; but it forms an excellent foundation upon which to build a practical knowledge of the business.

"Many of our mines are now under the direction of competent engineers, and the results of this policy are justifying the hope that, before very long, all companies of good standing will place their mines in charge of men specially trained for the discharge of the responsible and important duties of a mining engineer."

to be unlearned. The American mining-schools have already adapted themselves so well to their environment that this year, for the first time in nearly a century, there were no American mining students in the great Saxon *Bergakademie* at Freiberg. And already some of the American mining-schools have exceeded in wealth, in equipment and in attendance this most famous of all mining-schools.

Is Theoretical Training Worth While?

But, it may be urged, if practical men without theoretical training have accomplished so much, what is the use of theoretical training? Why not confine the education of the mining engineer to the purely practical part, omitting all the theory? The answer is not far to reach. The purely practical man has indeed accomplished wonders, but at the cost of enormous waste of money, labor and human lives. For every success that he has made there are a thousand failures which only the thoughtful notice. There is no profession where practical experience is more essential than in mining, but the necessity of a sound scientific training is even more indispensable. A hard-headed Arizona miner once put the matter very tersely when the superiority of the "practical man" was being strongly urged, by saying: "I have had thirty years' practical experience in mining, and I would give twenty-five of those years to have had a good technical education to begin with." He was clearly right, for a man well trained in fundamentals has a broader grasp and can more intelligently and rapidly utilize his experience than a man without this training.

Either theory or practice alone is helpless; united they are invincible. And the brilliant success of the American mining engineer in so many fields has been because these two important elements have been so thoroughly blended in his training.

Specialization, How Much and When?

This problem arises from the great breadth of training which has been necessary to the American mining engineer. Like the soldier or sailor, he must go to the ends of the earth. His work often lies beyond the borders of civilization, where, like Prospero upon his lonely isle, he must conjure up his resources from the vasty deep; and he must act in turn as geol-

ogist and as civil, mechanical, hydraulic, electrical, mining or metallurgical engineer. The problem is: what degree of specialization shall be undertaken in an undergraduate mining course? Shall we endeavor to turn out at graduation specialists, each completely equipped for work in some narrow line, or shall we rather attempt to establish a broad basal training in the physical sciences on which the future engineer may safely build, as circumstances may require?

The former system is the European practice, such parallel courses as mining engineering (further subdivided into coal- and metal-mining), metallurgical engineering (also subdivided into two branches), mine-surveying, mine-geology, and the like, being commonly-recognized departments within which the student specializes in an undergraduate course.

In an old community, where the mines are under government control, and customs have crystallized, such a specialization is wise. Each student can estimate with certainty the need for the specialty he chooses, and be sure of employment in his own line.

But under American conditions (with a few notable exceptions, where conditions have become relatively stable), it is unsafe to specialize too soon and on too narrow a basis. Here the mere specialist, outside of his specialty, is as helpless as a hermit crab outside of his shell, and unless he possesses the ability to adapt himself speedily to a rapidly-changing environment, is sure to go under. The present age in America is one of rapid change in all industrial and engineering methods, such as has never been seen in the world before. Old established processes are being continually swept aside and replaced by new ones. These changes occur with kaleidoscopic speed and unexpectedness; and the man who has painfully armed himself with precedent and ancient lore finds himself hopelessly beaten before he can even make a start in the race. The American has always been characterized by his fertility of resource and power of adaptation. This has been his strength; his weakness has been his impatience to plunge into practice without a sufficiently broad and deep scientific training.

Fundamentals First.

I believe that we can trust to the American instinct of adaptability without much further attention. But that which is

most necessary, is to insist more and more on a solid foundation of scientific training to begin with. If we can secure for the American mining student a foundation-training broad, deep and thorough in mathematics, physics and chemistry, he needs little else to make him invincible. The mining engineer must have a broader basal-training than either the civil or the mechanical engineer, even though he specialize less. Mathematics, physics, and chemistry are necessary for all engineers; but for the civil engineer mathematics is fundamental, for the mechanical engineer physics is equally so, while for the mining engineer we must not only add physics, but also chemistry and the closely related allies, mineralogy and geology.

The training of the mining engineer cannot be too thorough in all these subjects. Each is an essential support to any superstructure that he may desire to build in the future.

Mathematics should include the differential and integral calculus, the theory of probabilities and the methods and criteria of approximations. A firm grasp of space-relations, as developed in descriptive geometry, is peculiarly important in following geological structure and vein-formations in the deeps of the earth. The mathematical work should be made familiar by numerous applications to concrete cases in which numerical results should be insisted upon. In this connection it is particularly important that the engineer should be made to realize that the most important part of his numerical result is the position of the decimal point, and only after that, the value of the first significant figure. Mathematical instructors too often neglect this, to the engineer, most vital matter. The sense of it should be made instinctive. It is much more important that mathematical instruction should be thorough, as far as it goes, than that it should feebly cover a large territory. The subject should be so thoroughly mastered that it comes to fit the hand like a well-worn tool.

No man is fit to teach mathematics to engineers who has not had some experience in its applications either to engineering, to physics, or to astronomy. For only such a man knows just what to emphasize and what to omit, how to sympathize with, and how to inspire his students.

Men of prime ability in the mathematical faculty are absolutely the first essential in any engineering school. It is won-

derful how difficulties melt away like wax in the fire with a really able mathematical teacher. By such a teacher mathematics can be made as interesting as a romance to the average man; while it is often regarded as hopelessly difficult merely on account of the poor hands in which it is placed. To make new discoveries in the field of mathematics requires genius of a high order; but to master all the mathematics necessary for the intelligent practice of engineering requires no faculties beyond those of a logical mind, a certain power of imagination, and a reasonable degree of application. I have always found that the students who do well in mathematics do well in everything else that requires close thinking.

Instruction in physics and in mathematics should go on side by side; and the two courses should be so arranged that the mathematical principles may be at once applied to physical problems of a useful nature. The importance of actual numerical results should be always insisted upon. The student should be trained in the arts of observation and in inductive, as well as deductive, reasoning. He should acquire practice in the theory of approximations, and should form the habit of judging or "weighing" his own results, and of checking them by independent methods.

While the whole field of physics is important, the fundamental conceptions of analytic mechanics (acceleration, work, kinetic and potential energy) and their applications in hydraulics, thermodynamics, electricity and the like are vital, and cannot be too much emphasized.

Instruction in chemistry should be given parallel with mathematics and physics. It offers a fine training in inductive reasoning. Besides the usual courses in general and analytic chemistry, the modern methods of physical chemistry, as developed by such masters as Arrhenius, Ostwald, Nernst, and V'ant Hoff should be brought to the attention of the student, as soon as, by his collateral training, he is made able to understand them. It is not too much to say that the hope of the future, not only in biology, medicine and hygiene, but also in physical geology, the science of ore-deposits and the art of metallurgy, lies in this direction.

Such subjects as drawing, surveying, and mapping may also be carried on simultaneously with mathematics and physics,

each supplementing the other. Similarly, assaying and mineralogy give a new interest to chemical principles, to which they serve as useful applications. Geology itself, important as is this noble subject, not only through its intrinsic interest, but also in its practical bearings, is really only an application of the principles of physics and chemistry to the study of the evolution of the earth. And it can be mastered only by him who has this training to build upon.

The same is true of every branch of engineering. Each is only the outgrowth of the application of the principles of the fundamental physical sciences to the needs of man. He who has this training has the master-key to the door of every industry.

The necessity for thoroughness in this fundamental work cannot be too much emphasized in American mining-schools. The impetuous preference of young Americans for what they deem "practical" is a serious hindrance to real achievement; and the only way to remove it is to convince them, at the very start, of the power and value of science. This can best be done by leading them, from the beginning, to apply science to some useful purpose. In short, they must be taught by experience the truth of Ostwald's saying: "The science of to-day is the practice of to-morrow."

There is much to be said in favor of the study of science for its own sake. We have all sympathized with the sentiment of the mathematical professor who "thanked God that he had at last discovered something that never could be put to any practical use." Still, it is a healthful instinct that leads most men to estimate the value of ideas by the use that can be made of them, and whether we approve it or not, the world will continue to do that, and we may as well adapt our plans to the fact.

To the man thus fundamentally trained; nothing is impossible. He may still need to be made familiar with the general scope of each of the main branches of engineering, their relations to each other, the nature of the problems that each is called upon to solve, and the leading methods which, in each branch, have stood the test of time; and he should be made sufficiently familiar with the literature of the subject to know where to go for needed particulars; but any attempt to cram his memory

with the details of methods that may become obsolete, before he is called upon to use them, is a distinct and fatal mistake.

The Organizing Faculty.

The successful engineer is a creative artist in the use of materials and energy. In this class, he stands first, who, with the smallest means, produces the greatest results. Success will come most surely to him who clearly sees the nature of each concrete problem, and, from the widest outlook, chooses just the right methods, materials and forces of men and nature, to bring his undertaking to a successful issue.

Among engineers the creative or organizing faculty is a natural gift as rare as any other kind of genius. But fortunately it is a faculty most Americans have, at least in embryo, and it can be cultivated. All the work of a mining-school, whether in the basal sciences, or in the technical branches, may be utilized to develop it. Instead of possessors of encyclopedic erudition, there is needed a type of man that may mechanically remember less, but can do more. Such a man learns to analyze each problem that comes before him; when necessary, he runs down the literature bearing upon it; selects the good; rejects the bad; supplies by ready invention the missing link; decides what must be done;—and *does it*, cleanly, rapidly and with certainty, while the "encylopedio-maniac" is still digesting his erudition.

This kind of training, repeated again and again with every subject studied in the college course (at first in small and simple problems, later in larger and more complicated ones), does more to create the engineering faculty than anything else that can be devised. It is only by actually doing things that we learn how to do them. Action must follow reflection, and reflection must precede action for successful and useful life. Unless action follows reflection, life is "sicklied o'er with the pale cast of thought." Unless reflection precedes action we have all the ills that follow impetuosity, of which anarchy is the final and the bitter fruit. From this point of view, the training of engineers has a moral effect on the whole body politic, since it tends to create a solid, well-balanced element in the community. Nothing develops a good man sooner than responsibility, which forces not only reflection, but action also. And the

sense of power that comes with the successful exercise of the creative faculties in the engineering arts is one of the purest and keenest pleasures of which our nature is capable.

The greatest service those in charge of the higher technical branches of the mining-school can render their students, is to show them how to apply their scientific knowledge to such practical problems as come before them. He, who can do this for his students, and can give them a taste of that sense of power that comes from a mastery of the forces of nature, can trust them to go the rest of the road without a finger-post to point the way.

Personal Contact with Working-Conditions.

I have said that the mining engineer should learn to see clearly the problems that he must solve; that he must be familiar with the materials and the forces, not only of nature, but of human nature with which he must work. How shall he gain this knowledge? There is only one way: to become familiar with them by actual contact.

Should this experience come before, during, or after the college course? It is most useful when it comes in all three ways. But coming only after the college course, it is altogether too late. Before that course, it can be usually gained only at the sacrifice of that general training, particularly in the languages and the humanities, that is so important to us all; and, moreover, before college-age the student is usually physically too immature to undertake such work. For these reasons it is usually best to let this experience begin with entrance into the mining-school. In each college year, as commonly arranged, from three to four months are given to vacations, which, occurring at regular periods in summer and winter, are admirably adapted to a progressive course of practical work in surveying, mining and metallurgy, in which the student can familiarize himself with practical conditions in different localities. For the reasons already given, this work should begin with the school course, and be carried on progressively, at regular intervals, with the theoretical work. It is thus practicable for the student to gain nearly a year of experience in a considerable range of methods. He is thus in a position to determine his own fitness for the work; to learn the branches for which he is

best adapted, and for which there is most demand; and to make acquaintances that will be useful to him afterwards. If he shows aptitude for the work, he is reasonably certain of finding the place for which he is suited; and if he does not, he can adjust himself to some other calling without further waste of time.

The importance of this training for the mining engineer is greater than in any other branch of engineering; for the conditions that he must meet are entirely different from those of any other calling. But it has been much more difficult to secure it under American than under European conditions. Besides the lack of official connection between the mines and the mining-schools, there has been a strong prejudice against college-students on the part of practical men. This is partly due to experience with men trained exclusively in the old classical course, and almost helpless in practical affairs, because absolutely without knowledge or sympathy with nature. But it is also partly due to the self-assertion, flippancy and conceit of which young men just out of college are often guilty.

The "Mining-Laboratory."

Several solutions have been proposed to meet this difficulty. The first and most original is the so-called mining-laboratory, perfected through the pioneer work of Prof. R. H. Richards of the Massachusetts Institute of Technology. This has since become a prominent characteristic of American mining-schools generally, and is now being adopted in Europe. According to this plan, the leading operations of crushing, concentrating and working ores are executed by the students on a small working-scale in the laboratories of the school itself. In this way the schools have become partly independent of the mines, so far as the study of metallurgy and ore-dressing are concerned. In purely mining-practice the problem is more difficult. I have for ten years, with some success, made an attempt in this direction, so far as rock-drilling and blasting are concerned. For this purpose, a mining-laboratory has been provided, in which the operations of sharpening, hardening and tempering drills, and the single- and double-hand drilling of blast-holes, as well as machine-drilling, are illustrated on a working-scale. Later, with the aid of an experienced miner, the operations of blast-

ing are conducted by the students in a neighboring quarry. In the new mining building, provided for the University of California by the generosity of Mrs. Hearst, it is proposed to extend this work, as far as practicable, to other branches. These devices have all proved very useful in familiarizing students with important current methods, under conditions where they may be controlled and studied in detail, even better than in the hurly-burly of practice. The mining-laboratory is one of the most important of the efforts of American schools to adjust themselves to their environment.

The Summer School of Practical Mining.

But, helpful as this method has proved to be, it still fails to bring the student face to face with the actual conditions of mining practice. The next important step was taken by Prof. Henry S. Munroe, of the Columbia School of Mines. For many years he has devoted much labor, with notable foresight, judgment, tact and discrimination, to the system now known as the Summer School of Practical Mining. To him, more than to any other one man, we owe this very useful adjunct, which has been adopted, with various modifications, by most American mining-schools. It is an outgrowth of the geological excursion, so long practiced in German mining-schools. But here it has been made to comprise the study, by a body of students under the direction of their professors, of the leading operations of mining, dressing and working ores. One or more mining-districts and several mines are visited, during a trip of a month or more. Surveys are made; sketches and notes are taken; and the student begins to acquire a first-hand knowledge of many conditions which he must afterwards meet.

An interesting modification of this method has just been attempted jointly, at the suggestion of Prof. John Hays Hammond, of the Sheffield School, and under the direction of Prof. H. S. Munroe, of Columbia, by the mining-schools of Columbia, Colorado, Harvard, the Massachusetts Institute of Technology, and Yale. It consists in hiring a mine for the summer, and putting the students at work under proper direction at the various operations of practical mining. In this way the mine, for the time being, is turned into a sort of school for the young men. This change certainly has many advantages. It comes

as near the European conditions as is possible in America. It enables the operations of the mine to be subordinated for the time being to the needs of instruction. This, for beginners, is certainly a great advantage. The method is, however, an expensive one; and several years of experience are necessary before it can be finally judged.

There is another modification of the Summer School idea, perhaps even more difficult of general application, with which I have had the most experience, and from which I hope much in the future. I began by visiting with my students various mining districts each year; but I found in this plan not only many advantages, but also many serious difficulties. One of the most fundamental of the latter was; that there is an important element which a man does not get by merely looking on. He often thinks he understands a thing that he sees another do; but such superficial knowledge is not to be trusted. It may suffice for amateurs and *dilletanti;* but real professional knowledge and power are not so obtained. It leads to that false sense of knowledge that makes practical men so disgusted with the man just out of college. It is the thorough, ingrained mastery, which long familiarity with his work has given the practical man, that makes him superior in any emergency to the mere "looker-on in Venice." Moreover, traveling with a large body of students tends to emphasize the difference between the students and the miners, and to make each party self-conscious, and, to a certain extent, antagonistic. When many students travel together, they carry with them the college atmosphere, which is the very thing they need most to get away from, in their vacations. It is only when such a body of students is so diluted by dispersal among a large number of mines and miners who are *working* and *not playing* at mining, that they can be made to realize that they are not "the whole thing;" then, and then only, are they in a position to derive any real benefit from their experience.

These views were gradually forced upon me, as they doubtless have been forced on others, by a study of results. Moreover, as the number of students in the classes increased, I found it more and more difficult to secure accommodations for them in any but a few large mining-centers. This greatly limited the practicable scope and variety of the work.

But the cause that finally decided me to make a change was the lack of means, among some of the best students, to pay the expenses of such trips, in addition to those of the college course. Some of these men asked to be permitted to work for wages, instead of attending the summer school. This was done in certain cases; and I found at once such an improvement in the subsequent work of these students, that I decided to alter my general plan accordingly.

The method, as thus far worked out, is to require that each student shall spend at least a month underground in the study of practical mining. As a matter of fact, most of the students thus spend from six to eight months during their college course, and many of them even more. Each must prepare a well-written account of his experiences, together with an essay, on a subject chosen by himself from among those that interested him most. These papers are read before the whole class and are discussed and criticized by all. Many of them have been extremely interesting and instructive.

The students are not required to work for wages, and are even discouraged from doing so, unless they are physically mature, and have some familiarity with the work. But all are strongly urged to attempt this before they graduate. Most of them need very little encouragement; in fact, they take to it as naturally as ducks to water. There is a time in the development of a young man when hard work seems to be a physical necessity—an assertion of his manhood. It has even come to pass among us, that the young man who, from physical or other disability, does not do so, loses caste among his fellows.

There is of course a certain disadvantage in working for wages. A man has to do the same thing over and over again and is usually too tired to think much while doing it. But this objection is easily removed; for when, by a month or more of hard work, a man has established himself and paid his way, it is very easy for him to take further time at his own expense to get a general view of the work as a whole. Some men are of course physically unable to perform manual labor for wages. But, unless they are unusually well-adapted for the profession in other ways, such bodily weakness is generally an indication that they had better adopt a less strenuous occupation. I have never found that the men have been lacking

in mental grasp from having to work; though, naturally, one cannot do hard labor and take voluminous notes during the same day.

On the other hand, there are certain great advantages in working for wages. It gives a man a just self-confidence, as nothing else can. He feels, that no matter where he may be, he can hold his own among men as a man. He learns the point of view of the working-miner, and how to win his confidence and respect. He gains an inside knowledge of the errors and successes of mine-administration. He comes to know the meaning of "a day's work," the tricks and subterfuges by which inefficient workmen seek to evade doing their duty, and the way to treat such cases without unnecessary friction. Such an experience is sure to prove invaluable, when, as he grows older, he is himself entrusted with the management of men. He will be more likely to know how to avoid unnecessary conflicts with his men from having himself "borne the heat and the burden of the day."

As a rule, men without previous experience are put first at loading and tramming cars, and later, at single- or double-hand drilling, or as helpers on a machine-drill; while in small mines they often have experience at timbering or at the pumps. Many of the men are really able to earn full wages as miners, before they get through. Often, when hard pressed for resources, they work a year, or even two years, underground, thus earning enough to pay their way through college. This seems rarely expedient, except in cases of necessity. But there are some cases in which an excess of animal spirits finds in such a rustication a natural outlet; and the man is really made over again by such an experience.

The men are advised not to go in groups, but usually in pairs, since, in case of illness or accident, a faithful "pardner" is a great source of comfort. They are also advised to scatter in a thin skirmish-line over the whole mining-region west of the Rockies. Some go as far south as Mexico, others find their way to Cape Nome and the Klondike. Thus, like bees from the hive, they scatter over a wide area; each brings back honey of a slightly different flavor; and all benefit by this richer store.

Many difficulties were encountered, particularly at the begin-

ning, in carrying out this plan. Many still remain to be overcome before it can be perfected. It depends for success, not only on the goodwill of the miner and the mine-owner, but also upon the discretion and tact of the student. I have always found the miner, and nearly always the mine-owner, willing to help any young man of good physique and good nature, who was not overcome with a sense of his own great knowledge and importance. But, when a very young man sets out, unasked, to show another man, old enough to be his father, how to run a mine, there is naturally trouble,—as there ought to be. For the first lesson a young man has to learn, is the necessity of adapting himself to his surroundings, and of fitting himself into his place in the greater mechanism; and, until he learns this, his lot is likely to prove rougher in the mining-world than anywhere else.

There is much to justify the prejudice against a man who goes to college simply to escape doing his share of the world's work. Consequently, I have advised my students never to ask for work *because* they were college students, but simply because they were able and willing to earn what they were paid. In short, I have advised them to secure in their vacations the advantages of the "Wanderjahren" of the German apprentice. By scattering over a wide territory they are absorbed very naturally, and, as a rule, without much difficulty. Some of them have learned hard lessons not down in books, but it has done them good.

The men are all advised as to the principal precautions to be taken to preserve their health, the dangers they will have to meet and how to meet them. They are plainly told that unless they are ready to take the hard chances of the miners' life they had better choose some other occupation.

Among more than a thousand students, who have participated in this work during the last fifteen years, there have been but two serious accidents. Both of these were fatal. The victims were young men who had been working for nearly a year in the endeavor to earn enough money to pay their way through college. One was caught in a cave. The other, in firing a blast, had his candle blown out by the spitting fuse, and, in the darkness, was unable to reach a place of safety. But these very accidents have served to convince the mining-public that

the California boys were enough in earnest to face the dangers of the miner's life.

This attempt at a solution of the problem is not presented as a general one; it is probably better adapted to western than to eastern mining-conditions. It can only be applied when there exist a large number of mining-camps within easy reach of the mining-school. Its best feature is, that it falls in with the American idea of free initiative. Moreover, it serves admirably to select the fit, and reject the unfit, without loss of time. It also automatically adjusts those questions of supply and demand that are so hard to settle.

In spite of its many imperfections, the system is beginning to bear fruit. The opposition to college men is growing gradually less. It is found that most of them are in earnest, and are willing and able to work, and that some of them have ability. Before the term of work is over a man is frequently told: "When you have finished college, I may have something for you to do." Many a man has dropped in this way into just the place for which he was adapted.

In short, if the college man can overcome the prejudice against him, that often exists all too justly among men of affairs, by showing that he really is a modest, willing and capable man; his education will have its chance to count in the end, as it does more easily at the beginning, under old-world conditions. The only chance to make his start that the American mining student has, is to meet the practical man on his own ground. He can always do this if he has the courage to break the ice. It is better and easier for him to do this before he graduates than afterwards.

Physical and Moral Soundness and the Co-Operative Spirit.

Experience on these lines has emphasized the importance to the mining student of a sound and, if possible, a robust physique. By this I do not mean heavy muscles merely, but essential soundness of the vital organs, particularly those of digestion, circulation and breathing, and also the senses of sight and hearing. Important as these possessions are to all, to the mining engineer they are indispensable. An early physical examination by an experienced physician should reject all defective can-

didates as rigorously as is done in the army and navy. This should be followed by a thorough physical training, the aim of which should be the production of a sound, healthy man. Some instruction in the fundamentals of hygiene, the precautions necessary in the use of food and water, the precautions to be taken in malarial regions and some knowledge of the "first aid to the injured," are very useful to men who must often serve as leaders of a forlorn hope in a strange land.

Even more important than physical soundness is moral soundness. It is absolutely necessary that mining engineers not only see the truth, but speak it. Scientific training, when thorough, always develops one important moral trait. It helps to elevate the love of truth into a religion. This is its greatest moral service to society.

In this connection we are all under indebtedness to the late Mr. A. M. Wellington for his able articles on "The Ideal Engineering School."[2]

Speaking of the young enginneer, he says: "He must be truthful and worthy of trust, must mean what he says and say what he means. If he cannot do this he must be silent." And again: "All men whose advancement depends on those above them must not only *be*, but also *seem*, faithful to those above them."

He calls attention to the fact, that the lawyer, the physician and, to some extent also, the clergyman, depend for success almost entirely upon their individual knowledge and intellectual abilities. Such a man may or may not be personally agreeable to those for whom he works; it is his knowledge and his technical skill that we wish to utilize in an emergency. These are his own possession, and he can utilize them unaided and without the co-operation of others.

But with the engineer this is not the case. His work cannot be done except through the friendly aid, not only of many engineering co-workers, but also through the help of capital and labor, the two most difficult elements in our civilization. From the inception of the original idea to its final completion, men and money, brains and brawn, nature and human nature, must work together without friction for a common purpose.

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[2] *Engineering News*, vol. xxix., pp. 397, 418, 445, 538 and 565; also vol. xxx., pp. 12, 14, 56 and 116, 1893.

The young engineer must win the confidence of his superiors by a faithfulness and loyalty, free from subservience; he must secure the good-will and liking of his equals by frankness and openness of nature; he must command the respect of his subordinates by his evident mastery of his business, his sense of justice, his freedom from petty meanness, and his fearlessness in the discharge of duty. The man who cannot meet the requirements of any one of these three relations, no matter what his knowledge and technical skill, is sure to fail. And because they possess these qualities in a high degree, many men of very ordinary abilities often succeed as engineers, when men of superior genius lamentably fail.

When men must work together day and night, side by side, in intimate personal contact where relations of subordination and command necessarily must exist, there must be no friction. Even a slight uncouthness of nature, or rudeness of manner, objectionable personal habits, or lack of tact, become simply unbearable at such close quarters.

All this is most emphatically true of the mining engineer. No men except soldiers, sailors, explorers and astronomers are subject to such a strain on their endurance.

As has been already pointed out by Mr. Wellington, the cultivation of the social graces and amenities of life, for habits of personal neatness, for self-control and uniform good nature under conditions of hardship and privation, have always been recognized as essential qualities in the army and the navy. That it is possible to cultivate these qualities, even in the most heterogeneous material, is evidenced by the success of our military and naval academies in producing them in the average American youth. The raw material they have to work on is not different from that which goes to our engineering schools. But the results they attain in this respect are so decidedly better that there is no comparison. In most engineering schools these important qualities are simply ignored, and no attempt is made to cultivate them.

Where, as in many of the so-called "Land Grant Colleges," a certain amount of military instruction and discipline is required, the means exist by which these qualities may be cultivated to some extent. In the University of California such is the case; and I have always found that the mining students

who, by attention to such matters, succeed as officers, invariably take high rank in their profession in executive positions. It is one of the few chances men in college have of learning the arts of controlling themselves and others. There is no agent so effective in forcing men to realize the means and advantages of co-operation as rigid military discipline. For the wars and struggles of our race since primeval times have polished and perfected this method till it has reached a high state of efficiency. But it is difficult for engineering schools to give to it the time and attention that is possible in a purely military school.

Another important means of reaching this end is to be found in all athletic sports in which, as in base-ball, boating and especially in foot-ball, team work plays an important part.

Organizing students into parties for surveying and other field- and laboratory-investigations, where each in turn acts as aid and as chief, is another effective means. In short, any agency that develops the instinct of co-operation, of team work, of the faculties of self-control, courtesy, fidelity and faithfulness, will prove effective. It will be more difficult to secure these qualities in America than it is abroad, because of the strong instincts of individualism and self-assertion that are such marked characteristics of American youth. Nevertheless, the uniform success of Annapolis and West Point in these matters testifies to its possibility. There is great room for improvement along these lines in all American engineering schools.

Sundry Minor Essentials.

There are also certain minor matters, too often neglected by both students and professors, which are peculiarly important to the young engineer in his first work after graduation, and all of which can easily be mastered in college; such as: neatness in drawing, mapping and lettering; certainty and rapidity in numerical work, in the measurement of angles and distances in surveying, and in sampling, assaying and the common methods of analysis. At first, accuracy is more important than speed. But the latter is, in practice only, less important, and should be insisted on from the beginning. A sound judgment on the degree of precision needed for the particular purpose in question is also indispensable. The student should be sure, on the

one hand, that his errors do not exceed this limit, and, on the other hand, that he does not waste time in needless refinement when approximations suffice. He should form the habit of always checking his measurements and calculations by, at least, two independent methods. The only way to insure this standard of accuracy and dispatch is to hold him to the hard standard that he will have to meet in practice, and to make him realize, that for carelessness or blunders, no explanations can be accepted. Rigid discipline on these lines should begin in the mathematical, physical and chemical departments, and should run right through the higher technical work with increasing severity. Tolerance of blunders is cruelty in the end.

General Training.

The mining engineer needs a certain fundamental training in economics, by reason of his position as an intermediary between capital and labor, his necessary dealings with merchants and contractors, and his handling of questions as to the valuation of mining-properties and the financing of mines. Besides the broad questions of money, interest, wages and other leading topics of economics, it is also important that he should be familiar with the laws of specifications and contracts, of ordinary business usage, the science of accounting, and the law of mines and water.

The broader the general culture with which a student comes to the mining-school, the better. The minimum entrance requirement should include some familiarity with general history, with the best of English literature, and the command of a simple, clear and forcible English style. A reading-power of the leading modern languages is only less necessary than a mastery of one's mother-tongue.

As the training of the mining engineer must, of necessity, be chiefly scientific and technical, its natural tendency is to put him somewhat out of sympathy with the gentler side of human culture. It is important to counteract this tendency by keeping him in touch with the finer arts by which life is mellowed, enriched and ennobled.

Where, as is frequently the case in America, the mining-school is an integral part of a great University the scope of which includes all the activities of our nature, this end is easily

and naturally reached by the association of mining students with other students who are devoting their lives to the arts, or philosophy and letters. The student is thus forced to become familiar with a wider outlook. Some touch with one of the finer arts, such as music, painting or sculpture, that will bring out the innate love of ideal beauty that exists in every man, is necessary to a well-balanced nature. Perhaps the most important of these influences is the cultivation of a taste for general literature, whose possession is a refreshment to the soul. The mining engineer, who possesses it, takes with him to the ends of the earth an inspiration that must make him an agency of moral and spiritual uplift wherever he may be.

Location of Mining-Schools.

Which is the better location for a mining-school:—a mining-center, or a commercial one? Successful mining-schools have been established in the older countries in both situations; Freiberg, Clausthal, Przibram and Leoben are examples of the former; and Paris, Berlin and London of the latter. Historically, the first to be established were in the mining-centers, which have the advantage of surrounding the student with a professional atmosphere, in which all the activities and ambitions of life gather about this one industry. When means of communication were poor, such a location was almost indispensable.

But such a location tends to make the training of the mining engineer provincial when it should be universal. Moreover, even in Europe, an end comes at last to a mining-district, and the mining-school becomes stranded in a dying community. Some of the most famous of the European schools are already approaching this condition, which, yearly, becomes more desperate.

It is for this reason that the modern tendency is in the opposite direction. The most permanent of human institutions are the great commercial centers, made so by natural physiographic features, that facilitate intercourse, which is the life of trade. The capital that develops mines comes from these centers, and the profits from the mines return to them. The enterprise that undertakes great ventures has its source there,

and thence, confining itself to no national boundaries, reaches out to grasp the natural wealth of the world.

It is becoming more and more important that a mining-school should be located at the heart of things; for it needs to be not only permanent, but permanently strong, to maintain relations with capital not less than labor, and to have a cosmopolitan rather than a provincial outlook and sphere. It is as necessary as ever that the mining-school should be in close touch with many operating mines. But in modern times this is much more easily effected from commercial than from mining-centers. For these reasons, I believe that in the near future the positions of commanding importance will be held by mining schools located near large commercial centers, particularly when these command not one, but many mining-districts.

Over-Supply of Mining-Schools in America.

In a paper on "The Growth of American Mining-Schools and their Relation to the Mining Industry," read at the Engineering Congress at the World's Fair at Chicago in 1893,[3] I have already called attention to the relatively small proportion of miners among the wage-earners of the United States. According to the tenth census, the number was only 1.82 per cent. of the wage-earners, or 0.63 per cent. of the total population. The eleventh census showed a similar relation. The figures of the twelfth census show the total number of miners and quarrymen to have increased to 1.95 per cent. of the total wage-earners, or 0.75 per cent. of the population. It is impossible to determine from this report the exact number engaged in metallurgical work, but after a careful study of the data given, a liberal estimate for metallurgical laborers shows that the total for both industries cannot be much more than 2.5 per cent. of the wage-earners, or 0.95 per cent. of the population.

On the basis of the eleventh census (which contained no enumeration of mining or metallurgical engineers) I estimate that there could not have been at that time over 6,000 persons in the United States, who practiced these professions; and that to keep up the supply would require about 200 new men per year. In the twelfth census the mining engineers were

[3] *Trans.*, xxiii., 444; also, *Transactions of the Society for the Promotion of Engineering Education*, Vol. I., 1893.

enumerated for the first time, and the number given is only 2,908. Metallurgical engineers are not specified; but under the head of "Chemists, Assayers and Metallurgists" the number is 8,887. It is plain that a liberal outside estimate of mining engineers and metallurgists would be ten thousand; and to keep up the supply would take about 330 new men each year. By including assayers, mine-surveyors, and the various minor officials of mining and quarry companies, who might require some technical training, this number might possibly be doubled or even trebled. But when we remember, that, for many of these positions, very little training is required, and that they are open to anyone who wishes to attempt the work, including many mining students who fail to graduate, it must be evident that there is a legitimate field for not much over 300 mining-school graduates each year. In 1893 I showed that there already existed in the United States a much larger number of mining-schools than was really needed; and the number is now much greater. The attendance at many of these schools has already increased enormously. At the University of California, for instance, the gain has been nearly 1,400 per cent. since 1887. There is no doubt that the demand for mining engineers in America can easily be supplied by the existing schools. It would be a distinct advantage if they could be restricted to a very much smaller number. Not more than six, or at most a dozen, favorably distributed according to the needs of the mining communities, could do all the work demanded of them much better than a larger number. Under American conditions no regulation but that of natural competition is possible. Much could be gained, however, if the existing schools would co-operate to fix a common standard for the degrees given. While no official relation with the mines is possible, the moral effect of such a step would be very great.

Degrees.

One of the reasons that so little attention has been paid in America to college degrees in the past is the great unevenness of the requirements for them in different parts of the country. Wherever a degree, or its equivalent, has come to mean something definite, as with our military and naval academies, it has received full recognition.

Still, there are indications of a general change in the public estimate of degrees. This has been most marked in regard to those of Doctor of Philosophy and Doctor of Science, which have come to mean a capacity for original investigation in some branch of science or letters. It would be a distinct advantage to the mining-schools, and to the mining profession, if a similar definite meaning always went with that of the degree of mining engineer.

At present the practice of American mining-schools differs greatly in this matter. Some give the degree of mining engineer at the end of a four years' undergraduate course. One even gives it in three years; one has attempted a five years' course, but has unfortunately gone out of existence. Others give, for much the same amount of work, only the degree of Bachelor of Science at the end of the undergraduate course, and reserve the degree of Mining Engineer for advanced work.

I am convinced, that no matter how excellent the course of a mining-school, it is a distinct mistake to give the degree of mining engineer on the same basis as that of the bachelor's degree. Some engineering-schools, recognizing this difficulty, have attempted to institute as a mark of greater attainment the absurd degree of doctor of engineering.

The highest degree given by a mining-school should be that of Mining Engineer. This degree should be put on the same basis as that of Doctor of Philosophy, or of Science. It should be confined to those who have not only mastered the fundamental training, but have shown by actual accomplishment that they possess, in addition, the precious qualities of initiative and capacity as leaders in engineering, and also that maturity of mind and character which one naturally associates with the profession of the engineer. If this standard could be maintained, the degree of Mining Engineer from an American mining-school, in spite of its disconnection with government service, would soon stand higher than that of any other country in the world.

It must be evident that it is not possible to crowd a complete technical education into a four years' course, without neglecting the broad basal training that is necessary for advanced work. But, if some such plan as I have outlined were adopted

by the leading American mining-schools, a great advance would be made.

A large number of men could then take advantage of the undergraduate course which would then, in a new sense and in a much higher form, take the place of the *Bergschule.* In this school all would receive the fundamental training necessary for the mining engineer, together with some knowledge of the various technical branches. After finishing this course of four years, and receiving the bachelor's degree, the best thing for all to do would be, as a rule, to plunge directly into the realities of the mining life. All could then step at once into the lower ranks of the profession. Most would undoubtedly be contented to remain there, filling a useful place, in the general scheme, now occupied by men without either scientific or technical training; thus raising the standard of the entire industry.

But the chosen few, who possess the creative faculty of the engineer, should be encouraged to find their special bent and field as soon as possible, and then to throw their whole strength into a real mastery of the chosen specialty. A man is then in a position to specialize as much as may be necessary without becoming narrow. Three years of mature work along these special lines, in graduate work, either in college, or, under proper conditions, outside of it, should lead to the production of a piece of original work which would justly entitle him to the degree of Mining Engineer.

Such a policy would parallel, without imitating, the methods that have been so successful in encouraging advanced and independent workers in our Universities. It would create an American *Bergakademie* that would be superior to anything of the kind in Europe, and it would secure for America, by a process of natural selection, a body of mining engineers worthy of their natural heritage.

Notes on the Physical Action of the Blast-Furnace.*

BY J. E. JOHNSON, JR , LONGDALE, VA.

(Washington Meeting, May 1905)

It is the purpose of the present paper, while not excluding chemical considerations, to deal more extensively with some o the physical and mechanical aspects of the blast-furnace process, and to point out its dependence, in these respects, on well known laws.

The quantity and cost of ore and flux required to make ε ton of iron being determined by circumstances over which the furnace-man, under given conditions as to quality and quantity of product, has commonly little control, the principal item o cost, apart from the saving of labor, which he can aspire to reduce, is that of fuel.

To determine the limits of possibility in this direction i clearly the first step in a practical inquiry; and this step i represented herewith in Fig. 1, a diagram showing the tota useful effect obtained from a pound of fuel under various conditions, and thus permitting direct comparison, under any giver conditions, between actual results and the maximum possibl results. The following statements will explain the basis upo which this diagram has been constructed.

One pound of fuel, containing 90 per cent. of fixed carbo (which represents average conditions), is taken as the unit.

The degree of oxidation of the carbon is measured by th ratio of the two oxides of carbon contained in the top-gases It is necessary to remember that a considerable quantity (carbon is brought in as carbon dioxide by the flux, and to tak account of it and of its condition.

It is here considered that the carbon dioxide liberated b the limestone does not affect the analysis of the top-gases, an that the ratio of CO to CO_2 will remain unchanged by the ad dition of limestone; enough CO_2 being reduced by the solutio

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of carbon from the fuel to restore an equilibrium established by the conditions, the chief of which are the ratio of fuel and ore and the top-temperature. That this is the case in practice may easily be proved by letting a tube go down through the

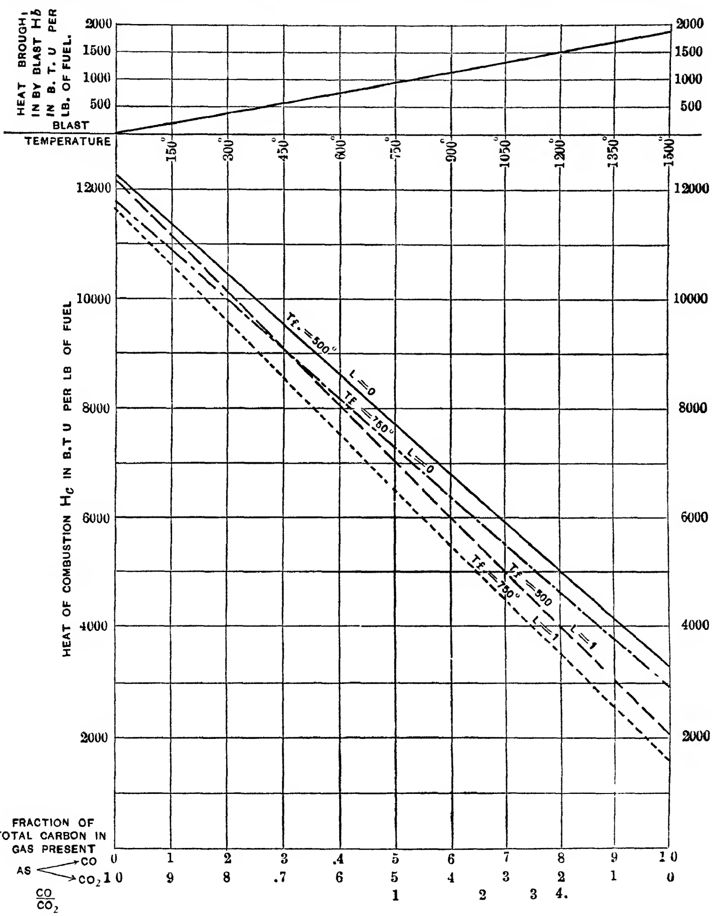

FIG. 1.—DIAGRAM SHOWING HEAT IMPARTED TO STOCK BY COMBUSTION OF 1 LB. OF FUEL (90 PER CENT. OF C) WITH DIFFERENT RATIOS OF CO TO CO_2; TOP-TEMPERATURES; WEIGHTS OF LIMESTONE PER POUND OF FUEL; AND HEAT BROUGHT ON BY BLAST, Hb.

top of the furnace in the stock, until its lower end reaches a zone where the limestone begins to be decomposed, and then taking gas-samples from its upper end and simultaneously from the top-gases. The proportion of CO_2 to CO will be notably

higher in the first than in the second. This result has been reached to my knowledge by three different experimenters working under very different conditions. In one of my own experiments, the gas from about 8 ft. below the top gave CO_2, 18.8, and CO, 21.0 per cent., while the sample taken simultaneously at the top gave CO_2, 13.4, CO, 25.8 per cent. This shows that the CO_2 evolved by the limestone is partly reduced to CO at the upper levels of the furnace. Further proof is afforded by the fact that furnaces, working under conditions otherwise similar, but with the ratio of limestone to coke varying from, say, 0.5 to 1.5, show practically the same ratio of CO to CO_2 in the top-gases.

In order to represent this condition on the diagram, lines are drawn representing the useful thermal effect with no limestone present, and with 1 lb. charged per pound of coke, the gases being discharged at 500° and at 750°, under each of the above conditions.

These lines show the quantities of heat developed and remaining in the furnace (that is, not carried off by the gases) for every ratio of CO to CO_2 from zero to infinity; that is, with the gas varying from all CO_2 and nitrogen, to all CO and nitrogen; and for the above four conditions. This quantity of heat will for convenience hereafter be denoted by H_c, the heat of combustion.[1]

In calculating the heating-effect when limestone is present, the quantity of carbon (0.12 lb.), brought in by 1 lb. of limestone, is added to the carbon of the fuel (0.9 lb.) and the sum divided in the assumed proportion between CO and CO_2. From the quantity of carbon corresponding to the CO_2 thus found, the 0.12 lb. introduced by the limestone is deducted (as it was introduced in the form of CO_2) and the heat of combustion of the remainder is calculated. To this is added the heat

[1] In these and all similar calculations in this paper, temperatures are given in Fahrenheit, and quantities of heat in British thermal units, unless otherwise stated; and the following constants are adopted as substantially accurate:

One pound of carbon burnt to CO_2 gives off, . . .	14,450 B.t.u.
One pound of carbon burnt to CO gives off, . .	4,450 B.t.u.
One pound of hydrogen burnt to H_2O gives off, . . .	61,560 B t.u.

(when the resulting water-vapor is cooled to 32°).

Air contains by weight 23 per cent. of O and 77 of N. Specific heats: O, 0 2175; N., 0.2438; Air, 0.2375; H, 3 409; CO_2, 0.217; CO, 0.2479; Coke, 0.21.

of combustion of the portion burnt to CO and also the heat brought in by the coke assumed at 70°, or 15 B.t.u. (All heat-quantities are figured from 0° F. and this small item is therefore properly introduced.)

The nitrogen present is calculated on the assumption that all the carbon is burnt to CO at the tuyeres, which is not strictly correct, but near enough for present purposes, as the correction would be so slight that its effect on the general result would not be noticeable.

The heat carried off by the gases is simply calculated from their respective weights and specific heats.

This omits the heat brought in by the hot blast; and since that is a large as well as a varying quantity, the amount brought in by the air necessary to burn 0.9 lb. of carbon to CO at different blast-temperatures, is given in a small supplementary diagram at the top of Fig. 1. This will for convenience hereafter be called H_b. It must be added to the quantity obtained from the main diagram for any given set of conditions.

No account is taken in the diagram of the heat necessary to dissociate the CO_2 from the limestone, which is given by the authorities as 666 B.t.u. per lb. of limestone. Under present conditions this work is actually done in the furnace, and it would not be proper to make the deduction from the "limestone" lines; but to make a correct comparison as between the lines showing the results with, and without limestone, this deduction should be made. The lines would then show the relative results of a furnace using calcined limestone and one using raw stone.

On the diagram and throughout this paper "T_f" stands for the temperature of the top-gases and "L" for the quantity of limestone per pound of coke. The ratios of CO_2 to CO are given beneath the percentages of these, and vertical lines are drawn to correspond with some of the former.

The loss consequent upon the introduction of limestone is proportional to the quantity charged, and for other amounts may be taken from the diagram by interpolation. The same statement applies to the effect of change in top-temperature, and by a double interpolation the desired result may be obtained for values of L and T_f, both differing from those given.

It will be seen from the diagram that the loss of heat, conse-

quent upon the introduction of limestone, is exceedingly large and increases rapidly as the percentage of CO_2 in the gas decreases. The loss would, of course, be considerably larger if the heat required to decompose the limestone were included, and is calculated to make the thoughtful furnace-man wonder if the often-discussed proposal to calcine the lime before charging may not have more in its favor than is commonly believed. This will be further discussed later.

The ratio of 1 to 2 is considered ordinary good practice. This ratio is said by Bell to be the highest which can normally exist, a statement to which I shall revert later.

It will be seen that for $L = 0.5$ and $T_f = 500°$, at this ratio, representing better than average conditions, H_c is 5,750 B.t.u., to which must be added the heat of the blast, the temperature of which we will assume to be 1,200°. This gives as the heat of the blast (H_b) from the diagram, 1,500 B.t.u. and makes 6,250 B.t.u. the total heat (H_t) received by the furnace from the combustion of 1 lb. of fuel. The diagram shows that if all the carbon were burnt to CO_2 this quantity would exceed 12,000 B.t.u.

This statement involves no assumptions as to the ways in which the heat is expended. It simply compares the maximum heat obtainable under the assumed conditions, with the maximum obtainable under theoretical conditions to which we might hope to approximate, if experience had not long ago discouraged us. The result is not flattering to the blast-furnace as a thermal apparatus.

We have, moreover, to bear in mind, that by far the most important blast-furnace fuel is coke, which represents, in good average practice, a diminution in weight from the original coal of not less than 33 and frequently 40 per cent. The portion of the coal so lost represents a combustible value per pound at least as high as that which is saved, and an efficiency as a reducing agent much higher, so that the performance of a coke blast-furnace, in practice at least as good as the average, represents a thermal efficiency of about 33 per cent.

From this point of view, there appears to be no theoretical impossibility of reducing still further the blast-furnace fuel-consumption of the present day.

If this be true, it may be practically useful to discuss in de-

tail certain problems of direct importance to furnace-men, such as the pressure of the blast, and the resistance to overcome which it is expended; the descent of the stock, and the origin and nature of "slips," as affected by the blast-pressure; and the effect of heating and of drying the blast.

The Blast-Pressure.

Disregarding the loss of pressure in stoves and blast-mains, let us consider the blast-pressure (above that of the atmosphere) in the bustle-pipe. This is expended in three distinct steps: (1) driving the blast through the tuyeres at the required velocity; (2) overcoming the frictional resistance of the column of stock in the blast-furnace proper; and (3) forcing the gas from the top of the stock through the down-comer and mains.

This last is so simple that misconception would have seemed impossible had the attempt not been made to deduce results as to the quantity of flue-dust carried over at different furnaces from their top-pressures. The truth is, that the top-pressure depends on the volume and density of the top-gases, and on the frictional resistance of the flues or mains through which they are forced, and on nothing else. The frictional resistance depends on the clear area, the length and the roughness of the mains.

Considering that the condition of the latter is generally a matter of entire uncertainty, as they vary in normal operation from perfectly clean to almost completely blocked with flue-dust and coke, calculations of the frictional resistance during operation are entirely worthless, as are also deductions as to the furnace-work from the gas-pressure. If the top-pressure rises, the blowing-engine automatically blows a little more pressure (never in good practice over a quarter of a pound) so as to maintain the same difference between the pressure at the tuyeres and that at the top. As these variations are much smaller and much slower than those due to other causes, they are naturally never noticed at the engine.

The pressure consumed in forcing the blast through the tuyeres has also come in for its share of misunderstanding. Within a few years the assistant to the superintendent (now superintendent) of the largest blast-furnace plant in the world contended with me strongly that the blast-pressure was nearly all

expended in forcing the blast through the tuyeres, and that the pressure at the top of the bosh would not be over 2 or 3 lb. in a furnace driven with about 15 pounds. He was, at that time, making experiments bearing on this subject, and soon found his error. This is, in fact, a matter on which we can make calculation with certainty;—Fliegner, Zeuner and Weisbach having made experiments on the flow of air through orifices, and established formulas there-for, which are authoritative.

The formula for this case is

$$W = 63.6\,A\,\sqrt{\frac{P_2(P_1 - P_2)}{T_1}} \qquad (1)$$

W being the weight in pounds of air passing each tuyere per minute; A, the area of the tuyere; P_1, the absolute pressure outside the tuyere; P_2, the absolute pressure in the furnace; and T_1, the absolute blast-temperature (Degrees Fahrenheit + 460).

One thousand cubic feet of air at normal pressure and 70° F. weigh exactly 75 pounds. Since this is about an average normal condition, the conversion of volume to weight can be conveniently made on this basis (and is so made throughout this paper). Moreover, since the tuyeres are usually circular in section, we can convert the above formula to a more convenient form for immediate use, as follows:

$$P_1 - P_2 = 2.4\left(\frac{T_1\,V^2}{P_1\,d^4}\right)$$

where V^2 is the volume of blast (free air) passing each tuyere per minute, measured in thousands of cubic feet, and d is the diameter of the tuyere in inches. This formula is not quite exact, being too high for low tuyere-velocities and too low for high ones; but it is accurate enough for the present purpose, under ordinary conditions.

For a furnace blown with 40,000 cu. ft. of blast per minute at 15.20 lb. pressure and 1,000° F. temperature, through twelve 6-in. tuyeres, we have $P_1 - P_2 =$ difference of pressure passing through the tuyeres =

$$2.4 \times \frac{1000 + 460}{15.2 + 14.7} \times \frac{(3.3)^2}{6^4} = 1.0 \text{ lb.}$$

This is the difference in pressure required to give the necessary velocity through the tuyeres, and is, of course, fixed by the temperature, pressure and volume of the blast, and the size of the tuyeres.

It will be seen that this pressure varies as the fourth power of the diameter of the tuyeres, so that it requires over twice the pressure to force the blast through 5-in. tuyeres under given conditions as to force it through 6-in. ones.

Other things being equal, the loss of pressure in passing the tuyeres varies as the square of the velocity; and the energy of the blast-jet also varies as the square of its velocity, hence the energy varies directly as the difference in pressure. This energy represents the ability of the blast-jet to overcome resistance in its line of action—in other words, its penetration; hence the penetration is proportional to the difference in pressure between the bustle-pipe or tuyere-stocks and the interior of the furnace. This explains the failure of many schemes of alternate small and large tuyeres, and tuyeres with flattened nozzles adapted to deliver a fan-shaped jet of air, which will cover the whole tuyere-plane equally (Gaines tuyeres). The difference of pressure, under given circumstances, within and without the tuyeres, is determined by the area of all the tuyeres, and hence the penetration in front of each of them is the same. Consequently, when alternate large and small nozzles are used, instead of the small ones throwing the air to the center and the large ones filling in the dead spaces between them, they all penetrate in figures of the same shape in the tuyere-plane; but the larger tuyeres make a larger and therefore longer one than the smaller,—an effect the opposite of that intended.

Similarly the Gaines tuyeres distribute the blast so that the proper amounts are started in each direction to fill the area in that direction, but as some of these areas are much longer than others, while the difference in pressure is the same within and without the tuyeres in all directions, the penetration is either insufficient in some directions or too great in others.

For each diameter of hearth, number of tuyeres and general conditions as to blast-pressure, kind of cinder, etc., there is a given diameter of tuyeres which will throw the blast to the center sufficiently, without allowing great dead spaces on the walls between the tuyeres. If the tuyeres be made smaller

than this, the force of the air-jet straight ahead will take an excess of blast to the center of the furnace and allow pilasters, so to speak, of dead material to form on the walls between the tuyeres, thus reducing the active area of the hearth and making the furnace work too hot at the center. If, on the other hand, the size of the tuyeres be increased, the blast-jets fail to reach the center, but spread out laterally to such an extent that they may even cut the walls between the tuyeres, while a cone of dead material forms in the center.

One of the best furnace-men in the country once told me that he had banked his furnace, cut through the jacket, and put in additional tuyeres; that, in cutting in for these, they had found something like 3 ft. of perfectly dead material on the walls, and that, after starting up, they had made nearly 50 per cent. more iron than the best they could do before. Naturally, he was a believer in multiple tuyeres, though not extreme in his views.

On the other hand many illustrations could be gathered in which, under circumstances at first sight not very different, the results were but slightly beneficial, or even objectionable.

The explanation is not difficult. In the case stated, the size of the tuyeres had probably been increased until they were as large as the blow-stocks and bustle-pipe connections could supply, and the velocity of the blast into the furnace could not be reduced by further increase in size of the tuyeres, although it was very much too high, and the blast was going up the center, while heavy pilasters had been built up between the tuyeres on the bosh-walls, as was shown by the depth of dead material cut through, before the fire was reached. When additional tuyeres were introduced, the velocity of the air-jets was diminished, and they were able to spread out laterally so as to melt off the pilasters, and increase materially the effective area of the hearth. But if the bustle-pipe connections and tuyeres had been enlarged, so that the proper quantity of air, at the required temperature and pressure, could have gone through them at the proper velocity, the results would have been in all probability, almost, if not quite, as good as those attained by the use of a greater number of tuyeres.

If now, thinking to profit by this example, some furnace-man whose furnace was already equipped with a proper size of tuy-

eres, had followed a similar course, he would have so far reduced the velocity of the blast-jets that their penetration would have been insufficient; and they would have spread out sidewise, scouring the walls between the tuyeres and allowing a cone of cold material to form on the bottom in the center. In such a case, unless the area of the individual tuyeres had been reduced in proportion as their number was increased, the condemnation of multiple tuyeres would have been as hearty as its praise was in the first case.

It is not to be overlooked, however, that, other things being equal, the area of the pilasters on the walls varies nearly as the square of the distance between consecutive tuyeres or inversely as the square of the number of tuyeres. On the other hand, it must be remembered that the saving in hearth-area obtained by increasing the number of tuyeres increases much more slowly with each increase in their number, and that the difficulty and expense of maintenance of the tuyeres increases with each increase in their number. It is therefore not strange that the best opinion tends more and more strongly to a moderate number of tuyeres.

Before leaving this subject, I wish to call attention to a simple means of determining the activity of the different portions of the tuyere-plane, which is, of course, a direct measure of the penetration, and therefore of the correctness of the nozzle-area. This method consists in passing a $\frac{3}{4}$- or $\frac{7}{8}$-in. rod through one tuyere, and pushing it through the column of stock as quickly as possible, until it strikes the far side of the hearth, leaving it from twenty to fifty seconds, and quickly withdrawing it. The relative temperatures it has reached at different points will be a correct measure of the activity of the hearth at the corresponding points.

I am indebted to Mr. Austin Farrel of the Cleveland Cliffs Iron Co. for this simple but effective expedient. When he told me of it three years ago, I believe it was very little known, though it has since come into use to some extent, but is probably still unknown to some who will be as glad to hear of it as I was.[2] The results shown by this test are sometimes surpris-

[2] Since writing the above, I have been informed by Mr. Frank Firmstone that this expedient has been described by French and German writers—in some cases, several decades ago.

ing. I have seen a rod which had been put into a furnace, blown with about 11,000 cu. ft. of air through six 6-in tuyeres, come out almost dead black, for 5 ft. in the center, and so nearly burnt in two at the noses of the tuyeres that it broke at those points when it hit the ground. (The opposite tuyeres were 8 ft. apart from nose to nose.)

On the other hand, a reduction of the size of the tuyeres to 4 in., while it showed much better results on the rod, and lowered the bottom of the furnace (which was high before), was succeeded after a few weeks by a considerably greater loss of tuyeres and coolers. This is believed to have been caused by the tops of the pilasters which formed on the bosh-walls, making gutters, which led all the dripping iron and cinder down on top of the tuyeres, and caused their more speedy destruction. The pilasters, of course, were formed by reason of the too great velocity and penetration of the blast-jets, as before explained.

It seems very probable, therefore, that, where furnaces have a small number of tuyeres, it is, on account of this secondary effect, unsafe to increase the penetration so much as to bring the test-rod to a uniform temperature clear across the hearth. In furnaces with more tuyeres, the pilasters, in consequence of their smaller cross-section, do not extend so far up on the bosh-walls, consequently this danger is much less serious. This is a point in favor of a larger number of tuyeres than six; but the necessity for this is now everywhere admitted, if large product be aimed at.

Having found that about 1 lb., of the total assumed blast-pressure of 15.2 lb., is consumed in driving the blast through the tuyeres, we may say that 14 lb. are used for forcing the blast through the column of stock in the furnace, and 0.2 lb. for forcing the gas through the flues.

The Descent of the Stock and the Cause of Slips.

In order to have a concrete example on which to base calculations, let us take, as representative of present conditions, the Isabella furnace, of which the more important data are given in Mr. Gayley's paper on the dry blast. (*Trans.*, xxxv., 746, 1042.) The lines of this furnace are shown in that paper.

Let us assume, for an average of summer and winter conditions, that the output is 400 tons per day; the burden per

10,000 lb. of coke is 22,000 lb. of ore and 5,500 lb. of limestone; the coke per ton of iron is 1,900 lb. and the ore per cent. through the furnace, to agree with the above assumption, 53.6 per cent.

The total content of 18,090 cu. ft. are divided as follows: 1,193 cu. ft. in the hearth, 3,087 in the bosh, and 13,810 in the shaft above the bosh.

Assume that coke weighs 28 lb., ore 135 lb., and limestone 90 lb. per cu. ft.—figures sufficiently exact for our purpose, then the volume of a charge will be 357 cu. ft. of coke, 163 of ore, and 61 of stone, or 581 cu. ft. in all. Each charge weighs (as charged) 37,500 lb.; hence the initial average weight per cu. ft. is 64.5 pounds.

The difference of pressure between the tuyere-zone and the stock-line is 14 lb., and this is evidently all used up in forcing the gas formed at the tuyeres through the column of stock.

(The bare statement of this fact seems to me sufficient to disprove certain recent hypotheses as to the wandering of the blast. That the flow of gas in different portions of any horizontal cross-section of the furnace may vary greatly as a result of defective filling or other irregularity in the distribution of the stock, or as a result of scaffolding, is unfortunately only too true; but that there is any disposition of the gas to travel first in one portion of the cross-section and then in another, casually, and without strong compulsion, as is implied in the use of the word "wandering," seems preposterous. If the resistance to its flow is so great that 14 lb. are expended in driving it 70 ft., or a pound for every 5 ft., it seems impossible to believe that the gas will voluntarily confine itself to a still smaller area of cross-section, and not utilize to the full all the space offered for its passage, unless absolutely prevented by some definite obstruction, such as mentioned above. If these dead areas exist, why does not the gas only 5 ft. below, under a pound greater pressure, flow to them and so bring up their activity to that of other areas beside them?)

In the absence of knowledge as to the rate at which the pressure falls, we may reasonably assume that it is proportional to the distance traversed. This gives a loss of 2.6 lb. to the top of the bosh, leaving a pressure at that level of 11.4 lb. more than at the stock-line. Leaving out of account what goes on below that level, it may be observed that, since the stock exerts

a resistance of this amount to the passage of the gas, the gas must also exert a resistance of an equal amount to the passage (descent) of the stock, since "action and reaction are always equal and in opposite directions." In this resistance to the descent of the stock will be found the cause of slips.

The weight of stock in the shaft of the furnace can easily be calculated from the weight and volume of the charge given above, but the result so obtained is entirely too high, for several reasons. In the first place, the ore swells enormously in volume under the action of the gas and the deposition of carbon. Secondly, the oxygen of the ore is nearly all removed, lightening it about 30 per cent. Thirdly, all the CO_2 of the limestone is driven off, lightening it 44 per cent.

It is impossible to express the sum of all these effects with quantitative accuracy, but if we assume that the ore doubles in volume, and that the limestone decreases 44 per cent. in weight, by the time the charge has reached the top of the bosh, and neglect all the other conditions, we shall certainly be on the safe side in estimating the total lightening effect.

This gives a final reduced weight of 47.2 lb. per cu. ft.; and if we assume the change to have occurred uniformly as the charge descended, we can calculate the weight of stock in the shaft, which will be, on this basis, 755,000 pounds.

The pressure of 11.4 lb. on an area of 21 ft. diameter gives a total pressure of 568,000 lb.; but the difference of pressure is all that counts, and each zone is a little larger than the one above, so that the whole difference of pressure only acts on a central area equal to that of the stock-line. A deduction of 184,000 lb. must therefore be made from this 568,000 lb., and the net resistance offered to the descent of the stock by the blast is thus 384,000 lb., which is more than half of the entire weight of the column of stock. From the unbalanced remainder must be deducted the weight necessary to overcome the friction of the stock on the walls, which it is not practicable to estimate in figures. Probably it is not less than from 10 to 20 per cent. of the weight of the column, and may easily be more. Assuming it to be 15 per cent., it amounts to 113,000 lb., which added to 384,000 gives 497,000, or about two-thirds of the total weight of the stock-column.

Under normal circumstances the remaining third of that

weight is enough to bring the column of stock down; but if any local derangement takes place, and the pressure ceases to fall at a regular rate, we have a condition the trouble-producing power of which is cumulative; for, owing to the increased resistance, the flow past the obstructed point is reduced, and with it the friction and counter-pressure below; while, owing to the damming action of the obstruction, as the engine continues to blow the same quantity of blast, the pressure soon runs up; and, as the velocity is reduced, the high pressure that normally exist only in the lower part of the furnace extends up under the obstruction. This compresses the obstruction more, and forces it more tightly against the furnace-walls, while at the same time, by reason of the greater pressure, it becomes denser, and offers still greater resistance to the passage of the gas, which in turn augments all the other effects, until the furnace is "stuck" tight. The "plug" is in a conical passage and cannot yield backwards; and things remain in this condition while the stock below continues to settle until a cavity is formed underneath the "plug." Finally, through some accidental weakness in the obstruction, or through the slacking of the blast and reduction of the pressure under it, which allows the plug to come loose, the condition is broken, and the suspended mass falls.

As to the cause of the violent ejections of stock, some of which take the bell along, there has been much speculation, and various explanations have been made, none of which have seemed adequate. The true explanation seems to be that the whole furnace below the plug is a reservoir of compressed gas (this being especially true of the cavity formed under the obstruction), and when this latter gives way it is like knocking out the keystone of an inverted arch under pressure; the instant the arch is broken the compressed gas has ample energy to carry away, in its sudden escape, part of the overlying stock.

The greater the cavity the longer the "blow"; while the further down in the furnace the obstruction lies, the higher the pressure under it is likely to be, and the greater is likely to be the mass of material above it, through which the gas must make its exit, and portions of which it will carry along.

There come, however, occasionally, occurrences of this general type, but of so much greater violence and destructive

effect than mere "slips," that they seem to require a further explanation.

This seems to be furnished by the fact that the conditions I have described may occur at any point in the furnace, and that the deeper they are the greater is the air-pressure, and also the weight of the ammunition in the air-gun thus formed; hence the greater the execution. But if this occurrence takes place so low in the furnace that the cavity formed reaches finally down to the tuyeres, a further condition arises, in which the cavity is filled not with gas but with air; and when the break in the obstruction comes, the carbon dust, always present in the lower part of the furnace from the splitting up of the CO, is precipitated (along with the other materials) into an atmosphere of compressed and heated air, giving precisely the conditions requisite to the production of an explosion of great violence, in which case the air-gun becomes a powder-gun, and is not infrequently burst by the charge. This accounts completely for the observed phenomena of these more violent occurrences.

As already explained, the "kicking," due to slips, is more violent and prolonged in proportion as the obstruction is deeper in the furnace. But there is still another reason for the shades of increasing violence, which makes it almost impossible to tell where slips end and explosions begin; that is, the varying quantity of unburnt air in the cavity above the tuyeres, and the degree of its admixture with other gases. This is due to the gradual decrease in the depth of the layer of coke above the tuyeres. When this is no longer sufficient to form CO with all the oxygen, CO_2 appears; and when there is not enough coke to combine with all the oxygen to CO_2, free oxygen appears, and thereafter steadily increases. It is evident that the precise point in this series of changes at which the slip takes place will influence profoundly the character of an explosion, and even the possibility of its occurrence.

To the initial increase in resistance to the passage of the gas several causes may contribute; but, if the furnace is not scaffolded, the most important one is the deposition of carbon-dust through the splitting up of the CO into CO_2 and C. Both the extent of this action and the time of its beginning vary greatly with the character of the ore through which the gas passes, as

has been shown in various papers read before the Institute and elsewhere. It has also been shown that the action proceeds with great rapidity when it has once begun, thus localizing it in some cases to a certain restricted zone in the furnace, both below and above which the charge is more open—below, by reason of its downward movement and the increased shaft-diameter reached thereby; above, because no carbon has yet been deposited in it. The slips thus tend to be localized in this zone; and hence most of the slips from a given furnace, which slips habitually, would have about the same degree of violence. Practice shows this to be the case.

The recognition of this action, though tardy, is now so general, and the demand for increased outward "batter" in descending furnace-lines is so common, that it seems appropriate to recall that Mr. F. E. Bachman, seven or eight years ago, suggested that a furnace with a large batter immediately below the stock-line, and a much smaller one thereafter, would probably meet the conditions best. So far as I am aware, no one has had the courage to carry this idea to any considerable length; but the short steps taken in this direction have proved, I believe, entirely successful.

The connection between slips and that bugbear of the furnaceman's existence, "dirty coke," deserves mention.

On its way to the hearth, coke is always dissolved to a certain extent by the current of ascending gases. One of the principal factors in determining the extent of this action is the proportion of surface to volume of the individual pieces. If, for instance, in a given case, coke is charged in 6-in. spheres, and $\frac{1}{4}$-in. is dissolved from the whole surface of each before it reaches the hearth, its quantity will be reduced in the ratio of $\left(\frac{5.5}{6}\right)^3$, or to 77 per cent. of the original amount. But if the average size becomes 4.5-in. instead of 6-in. spheres, the amount of coke reaching the tuyeres is reduced to 70 per cent.; while, if it was originally dirty, and a large proportion of it was fine, the case is much more serious. For instance, if a part of the coke were 1-in. spheres under the same conditions as above, only one-eighth of that part, and if $\frac{1}{2}$-in. spheres nothing at all, would reach the tuyeres.

The result is not only a serious loss of heat, suffered by the

hearth, but a considerable augmentation of the quantity of CO in the gas, which in turn leads to a much more extensive deposition of carbon in the descending column of stock. This is carried down toward the hearth; but by its very fineness assists in maintaining the solvent action and the subsequent redeposition, so that the same carbon may go through this vicious cycle more than once. The effects of bad coke may thus be possibly cumulative; and when the deposit of carbon has become heavy enough to obstruct seriously the passage of the gas-current at a comparatively low zone in the furnace, all the conditions are at hand for a slip and explosion, of violence in some degree proportional to the quantity of carbon-dust present.

It may not be amiss to point out here a probable connection between these facts and the often-observed phenomenon, that, when a furnace gets very "hot," the pressure is apt to go up. When this condition exists, the gas passes out of the bosh at a higher temperature, and dissolves more carbon, which is again deposited above, choking the interstices of the stock and returning part-way to the hearth, to repeat the cycle as long as the conditions permit. The rise of pressure, and the occasional sticking and slipping to which it gives rise, are the direct consequences of this action.

Further argument in support of the theory of slips, given above, will not be offered here. It is to be noted, however, that, with the introduction of fine ores and of hard driving, not only in this but other countries, a marked increase in blast-pressure simultaneously occurred, and *pari passu* with these changes came slips and explosions. So long as the tendency to stick, and therefore to slip, was met solely by the introduction of engines of greater power, intended to drive the furnace whatever the pressure, slips and explosions continued unabated, or even increased in consequence of the higher pressures blown; but when the conditions began to be met by more rational furnace-lines, the pressure fell, and slips simultaneously decreased in number and violence.

The Results of Heating and of Drying the Blast.

The explanations offered by writers on the blast-furnace to account for the economic effect of heating the blast are non-

quantitative and therefore inadequate. The following paragraphs, translated from Ledebur,[3] give perhaps the best example:

"When, later, systematic investigations of the influence of the hot blast began to be made, the surprising fact was frequently observed that by heating the blast more fuel could be saved than was necessary for the production of the heat brought in by the hot blast. Moreover, it was very generally observed that the top of the furnace became cooler the more the blast was heated

"The two phenomena bear a close relationship to each other. The furnace requires, for each kilogram of iron produced, a certain quantity of heat, and the production of this heat, as has been mentioned earlier, is the primary purpose of the combustion of the fuel by the blast. Each kilogram so burnt furnishes a definite quantity of gas which ascends into the furnace

"But now, if a part of the required heat, instead of being produced by the combustion of carbon, be brought in by the heated blast, the resulting quantity of gas must be as much smaller as corresponds to the saving in fuel; the smaller quantity of gas gives up its heat more quickly and completely to the counter-current of descending solid material than does the larger quantity of gas resulting with the cold blast.

"The heat is accordingly more advantageously utilized in operating with hot blast, and, by this means, a secondary saving in fuel is made. The consequence of this is that the gas leaves the furnace in a cooler condition, and the top temperature falls."

Bell's explanation is not very different and no more satisfactory.

A simple explanation, which affords a basis for quantitative estimates in close accord with the actual facts, is afforded by considering the temperature at which a part of the total heat must be applied.

In the application of heat to the generation of power, it was realized more than a century ago that the temperature of application was of equal importance with the quantity of heat; and it seems remarkable that, in metallurgy, attention is rarely paid to the temperature at which the heat must be applied for the accomplishment of a given purpose, and that quantitative data bearing on this subject are practically unknown.

Calculations of the total quantity of heat imparted to the furnace by the combustion of one pound of carbon, such as those embodied in Fig. 1 of this paper, have frequently been made; and in a few cases calculations have also been made as to the maximum temperatures obtainable under various conditions, but if there have ever been any calculations as to the

[3] *Handbuch der Eisenhüttenkunde*, 4th ed., vol. ii., p. 577 (1902).

quantities of heat available at different temperatures, I have never heard of them.

The point of view from which this subject should be considered differs so slightly, but so radically, from the common one, that the distinction is not easy to make clear, but may perhaps be best approached by the conception of a "critical" temperature. It may be said without reservation that for every set of furnace-conditions there is a certain critical temperature, *above which only*, certain necessary operations of the process can be carried out. It is not necessary to know what the operations are, and no attempt will be made to enumerate them here, further than to say that they probably comprise the removal of the final traces of oxygen from the ore, the formation and subsequent superheating of the cinder, and the melting, carbonization and superheating of the iron,—"superheating" being used in the sense of heating above the point of fusion.

Given the existence of such a critical temperature, it is easy to see that where the heating is done by direct contact with the combustion and its products, as in the bosh of a blast-furnace, the only heat available for performing the operations which must take place above the critical temperature is the portion left after deducting the amount necessary to raise the products of combustion to that temperature. Or, to state the proposition in another way, if all the heat developed by combustion passed into the products of combustion, there would be available for the work of the hearth only that portion, the removal of which would suffice to reduce the products of combustion themselves to this critical temperature.

It is obvious that the nearer the critical temperature is to the theoretical temperature of combustion, the smaller will be the quantity of such available heat. If the critical temperature is, say, four-fifths of the theoretical combustion-temperature, then the available heat is only one-fifth of the total; and while the other four-fifths are useful for other purposes, they are lost for those under consideration.

The critical temperature varies in the same furnace with varying conditions, but for certain conditions it was determined to be about 2,750° F., as a probable average, and results obtained from calculations made on this basis were in such close agreement with actual results, that the series was extended to

cover other conditions; namely, two other critical temperatures, and varying quantities of moisture in the blast.

Such calculations are extremely simple and involve no uncertain assumptions, the method being as follows:

The combustion receives heat from three sources: the heat of combustion of carbon to CO; the heat brought in by the blast; and the heat brought in by the fuel. The latter may reasonably be assumed to be brought up to the critical temperature by the gas leaving the bosh, as the heat-exchange is a true counter-current one, and the contact is intimate.

The heat brought in by the coke is therefore 2,750 × 0.21 = 577.5 B.t.u., the heat of combustion of 0.9 lb. of carbon is 4,450 × 0.9 = 4,005 B.t.u., and the heat brought in by the air at 70° F. (cold blast) is 5.22 × 0.2375 × 70 = 86.8 B.t.u., a total of 4,669.3 B.t.u.

The products of combustion are 4.02 lb. of nitrogen and 2.1 lb. of CO; to heat these to 2,750° requires respectively 4.02 × 0 2438 × 2,750 = 2,695.2 and 2.1 × 0.2479 × 2,750 = 1,431.6 B.t.u., a total of 4,126.8 B.t.u., which deducted from 4,669.3 leaves 542.5 as the available heat above 2,750°.

Now assume the blast to be heated to 1,000°: the heat brought in by the blast becomes 1,241.8 B.t.u., or 1,155 B.t.u. more than before, the other items of heat brought in remain the same, as do those of heat removed by the products of combustion; consequently, the available heat is increased by this amount, which is a little more than twice the original amount, making the available heat in this case 1,697.5 B.t.u., or more than three times that in the previous case.

A series of calculations were made on this basis for different blast-temperatures, and also for different critical temperatures; these are given in graphic form in Fig. 2.

It is perfectly obvious that the higher the critical temperature, the less the available heat will be for a given blast-temperature, and vice versa.

The modification introduced by variable moisture-content in the blast is not quite so simple, but not in the least complicated.[4]

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[4] As the subject of the moisture in the blast is here discussed at some length immediately after the publication of Mr. Gayley's epoch-making paper, "The Application of Dry-Air Blast to the Manufacture of Iron," it seems proper to say

By way of preliminary, it may be explained that the unit of moisture in the blast here adopted is 1 lb. per 1,000 cu. ft. of air, since the latter is the unit of blast-measurement. There being 7,000 grains in a pound the commonly-used unit of grains per cu. ft. may be reduced to that here used by simply dividing by 7.

I had, for several years past, investigated the subject of the amount of the moisture in the atmosphere as measured by local determinations of the dew-point, and as taken from the records of the Weather Bureau, with a view of determining the effect of a given weight of water-vapor on the economy of the furnaces, the ultimate object being to find the relation between the cost of removing the moisture and the value of the saving so made.

Curves of fuel-consumption for the year, taken from the furnace-books for the corresponding weeks in several years and averaged, were of exactly the same general shape as the curve of annual humidity, but, the calculation of the effect of the humidity, on the basis given by Bell,[5] failed to account for more than a small part of the effect produced.

No adequate explanation was forthcoming until an analysis of the top-gases was made, which should have showed a very considerable quantity of hydrogen based on the moisture-contents of the blast, but which actually showed very little. This proved very clearly that the hydrogen, formed at the tuyeres by the dissociation of the moisture, took oxygen from the ore at a higher level in the furnace, where the temperature was sufficiently low to permit the simultaneous existence of water-vapor and carbon; and that in this operation the hydrogen re-

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that all the results here given were computed three years ago, as dated and registered copies of the diagrams in the possession of friends will show. As I shall discuss Mr. Gayley's results rather freely, it may not be amiss to explain also that I began working up the system of drying the blast by refrigeration in 1895, collecting data as to moisture in the atmosphere and in the engine-room, working out the whole scheme complete, with approximate cost and savings ; but when I applied for patents in 1897, I found Mr Gayley had pre-empted the claim in 1894. These facts are stated both as a full and complete acknowledgment of Mr. Gayley's priority, and to explain what may seem to others my undue familiarity with another man's subject.

[5] This method consists in the deduction of the heat of dissociation of the water introduced per pound of fuel from the total heat developed by the combustion of the fuel.

stored as much heat as the original water-vapor had absorbed for its dissociation, so that the explanation of the loss caused by

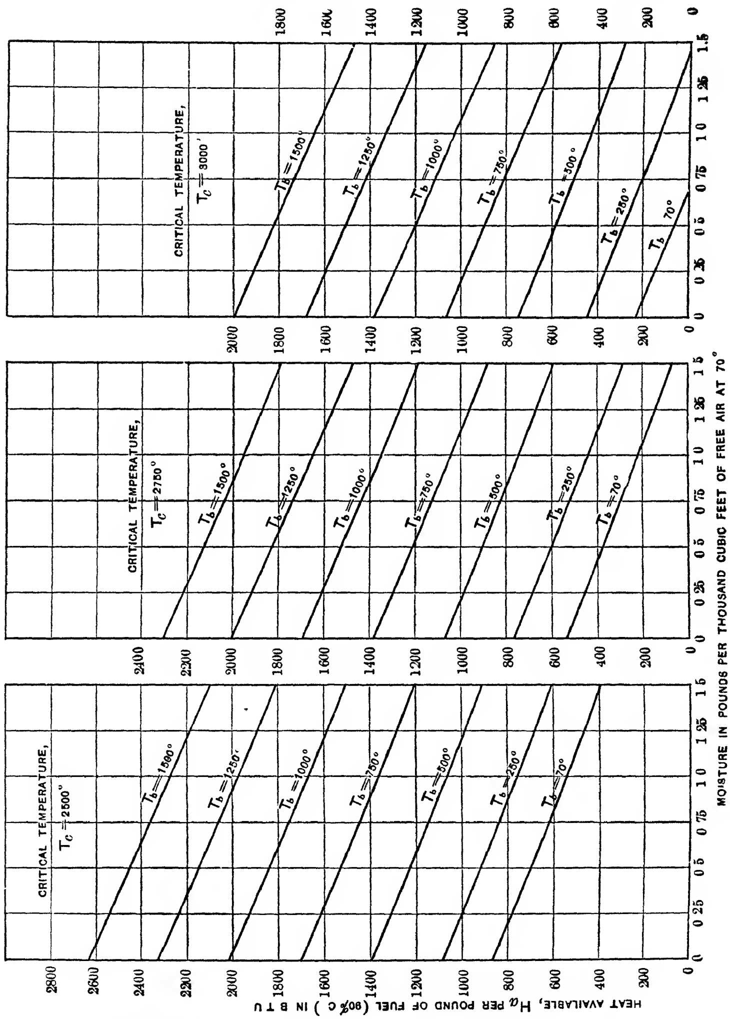

FIG. 2.—DIAGRAM SHOWING HEAT AVAILABLE (Ha) PER POUND OF FUEL (90 PER CENT. C) ABOVE THE CRITICAL TEMPERATURE, WITH DIFFERENT BLAST TEMPERATURES, WEIGHTS OF MOISTURE IN THE BLAST AND DIFFERENT CRITICAL TEMPERATURES.

the presence of water, mentioned above, was not the true one at all.

It then became clear that the heat was absorbed at the tuy-

eres or in the bosh during the process of combustion (it being entirely impossible for water-vapor to exist in the presence of incandescent carbon), and, being a first charge on the assets of the combustion, was deducted from the already scanty supply of available heat, so that its effects were of the same order and degree, but of opposite kind from those produced by hot blast.

The calculations of available heat with moisture present have to be modified from those of dry blast, because part of the oxygen required for the combustion of the carbon is furnished by the moisture, and the air required per pound of fuel is accordingly diminished.

To illustrate, let us take the case of air containing 0.75 lb. of moisture per 1,000 cu. ft. or (on the basis previously explained) per 75 lb. of air, corresponding to spring and fall conditions, with blast and critical temperatures as before, 1,000° F. and 2,750° F. respectively.

The oxygen in 75 lb. of air is 17.25 lb. and in 0.75 lb. of water is $\frac{8}{9} \times 0.75 = 0.667$ lb.; that is, $17.25 \div 17.917 = 96.28$ per cent. of the total oxygen is in the air.

The air per pound of coke is therefore $0.9628 \times 5.22 =$ 5.022 lb. and the heat brought in by it is 1,192.7 B.t.u.

The total heat of water-vapor per pound at 1,000° is 1,552 B.t.u., and the water-vapor being just 1 per cent. of the air by weight, the quantity brought in is 0.0502 lb., so the total heat brought in by it is 78 B.t.u. The heat of combustion and that brought in by the coke remain the same, so the total assets of the combustion become 6,152.6 B.t.u.

The heat taken out by the nitrogen is 2,594.6 B.t.u., that by the hydrogen is 52.4, and that by the dissociation of 0.0502 lb. of water is $\frac{0.0502}{9} \times 61,560 = 342.5$ B.t.u. The heat removed by the CO is, as before, 1,431.6, or a total thermal expenditure of 4,421.1 B.t.u., leaving as the heat available 1,431.6 B.t.u. against 1,697.5 B.t.u. with dry blast; all other conditions remaining the same. This is a reduction of 15.6 per cent., just about the difference in fuel-consumption that is found in practice under the given conditions. If the same loss were referred to the 6,000 B.t.u., which represent the approximate total heat-development from one pound of fuel, the loss would

be 4.4 per cent., which is an insignificant fraction of the actual results in practice.

The results given in Fig. 2 were obtained by a series of calculations similar to the above.

It is hoped that these diagrams will have more than an academic interest to furnace-men, as they furnish an easy means of determining the probable results in fuel-economy of any change in the temperature or humidity of the air. They also furnish the means of determining the increase in blast-temperature necessary to counteract the effects of a given variation in moisture. While it does not at first sight seem likely that we shall ever obtain stove-men who will determine the moisture from hour to hour, and proportion the blast-temperature to meet it, the thing is not impossible; and if some genius would kindly invent a recording and direct-reading instrument for measuring the humidity of the atmosphere, this result might be achieved in fact.

These results, being based on what is supposed to be a new theory of the action of heat and moisture in the blast, will naturally be viewed with some scepticism, so that proofs of their substantial accuracy are in order.

Fortunately the data supplied by Mr. Gayley furnish an admirable opportunity. The critical temperature alone is lacking, but, from the kind of iron made, may be assumed to have been 2,750° F. The humidity, before the dry blast was used, averaged about 5.25 grains per cu. ft., or 0.75 lb. per 1,000 cu. ft., and the blast-temperature was 720° F. After the application of the dry blast, the humidity was about 2 grains, or, say, 0.3 lb. per cu. ft., and the blast-temperature was 870° F. By interpolation on the diagram, we find the available heat in the two cases to be 1,090 and 1,420 B.t.u. per pound of fuel respectively. The coke-consumption before the change was about 2,140 lb. and, to be in inverse proportion to the available heats, should have been 1,640 lb. after the change. Actually it was 1,700 lb., a difference which is certainly no larger than might reasonably be expected, considering the many other factors varied. Notable among these is the increased ratio of CO_2 to CO in the top-gases, with the correspondingly increased tendency of these gases to dissolve carbon from the fuel in the upper part of the furnace, and prevent its reaching the hearth.

This feature, of which, obviously, the diagrams can take no cognizance, is of the first importance in an exact determination of results.

At many works the effects of the higher humidity of the summer are masked by the fact that the furnace-man carries a higher heat in summer than in winter, either deliberately and for the purpose of neutralizing the effect of the humidity, or simply because he finds that the furnace will stand more heat without sticking or other objectionable results. But, at the furnaces with which the writer is connected, a constant temperature of 850° is carried the year round, and under these conditions, the variation in fuel is clearly apparent; the fuel per ton of iron being about 20 per cent. more in the most humid weather than in the dryest. The critical temperature at these furnaces is known to be about 2,750° F.; the average low humidity is about 0.25 lb. water-vapor per 1,000 cu. ft., and the average high humidity is about 0.95 pound. For these conditions we find from the diagram that the available heats are 1,400 and 1,160 B.t.u., which are in the ratio of 1.20 to 1, or precisely the same as the fuel-consumption in the two cases.

In order to obtain a wider range of comparison, I have taken the work of a two-weeks period in two successive years (at precisely the same season in each) done by a small charcoal blast-furnace, working with cold blast one year and hot the next.

The comparison is not very satisfactory, because the critical temperature could only be obtained approximately in one case and estimated in the other, the percentage of lime used being twice as great for hot blast as for cold, with a correspondingly great influence on the critical temperature (as will be explained presently). Moreover, in the cold-blast campaign a considerable quantity of cold slag was charged, to overcome the tendency to work "dry," which was not done in the hot-blast campaign.

The recorded fuel-consumption in the two cases was in the ratio of 1.7 : 1, while the available heats based on the probable critical temperatures in the two cases and without allowance for the remelting of the additional slag in the cold-blast campaign are as 1 : 2;—a reasonable correspondence, considering the circumstances.

I recently found what appeared to be an authoritative statement, that, at the Clyde Iron Works (England), the fuel-consumption in January–August of 1829, 1830 and 1833 with cold, warm (300°), and hot (600°) blast respectively, was 8 t., 1 cwt., 1 qr.; 5 t., 3 cwt., 1 qr.; and 2 t., 5 cwt., 1 qr., or fuel-consumption in the ratio of 3.42 : 1.56 : 1, while the available heats, with a critical temperature of 2,750° and average moisture, are as 1 : 1.73 : 2.63, a correspondence which is not by any means accurate, but considering the magnitude of the saving and the probable effects of secondary results is not at all to be despised.

Other considerations of the same general kind in which the data are not available for quantitative comparisons will be given later, but will best be preceded by some remarks on the determination of the critical temperature.

Determination of Critical Temperature.—The paucity of published data of definite character on this subject led me to attempt direct experimental determinations.

This seemed a field in which a radiation pyrometer might be employed more conveniently than any other, and with the advantage of absolutely self-luminous bodies to observe. Accordingly, a Mesuré & Nouel "lunette" pyrometer was obtained. This instrument is not exact, and, for wide ranges of temperature, particularly at the upper or lower extremities of the scale, could not be trusted very far; but, for a limited range near its center, results obtained by any reasonably careful observer are closely comparable.

Many thousand observations were made with this instrument upon the iron and the cinder, where they flowed over their respective dams, at every stage of many hundred casts.

At first no connection whatever could be observed between the condition of the furnace, the kind of iron being made, and the reading of the pyrometer. Sometimes, it would show much higher temperatures with white iron than with gray, and again, it would give the opposite result, until I almost gave up hope of getting any information as to the action of the furnace from it. But finally, I observed that the readings were influenced almost solely by the relative calcareousness or siliceousness of the slag; and the difficulty of interpretation then disappeared.

One or two things were eventually brought out with great clearness, which are not recorded elsewhere, so far as I know, and are therefore given here, since, though they may be known to others, their publication may still serve to bring out valuable discussion.

The first point noticed was the absolute collapse of the old notion that gray iron was always made in a hot furnace, and white iron in a cold one. (The furnaces were working on basic iron, and the silicon was therefore limited to 1 per cent., so that gray iron in this case means iron with only about this percentage of silicon.)

The next observation was that, in spite of the common statement that black cinder is made because the furnace gets too cold, the black cinder, in reality, was very frequently much hotter than the light-colored one.

On the other hand, the old founders' saying that "lime gives heat to the furnace" was confirmed completely, the cinder being, without exception, hotter, in proportion as it was more limy, as long as the furnace continued to make good iron. Even when the iron became hard, the cinder might still be at its very hottest if very limy.

It was also noticed that the cinder always controlled the temperature of the iron, and that as long as no cinder came through the tap-hole the temperature of the running iron remained practically constant, but, as soon as the cinder came, the temperature of the iron went up considerably and became the same as that of the cinder, which was always decidedly higher than the previous temperature of the running iron.

These observations, confirmed so many times that their accuracy for the given conditions could not be questioned, made it plain, that, since the cinder became less fusible as it became more calcareous, it remained longer in the bosh, exposed to the heating action of the ascending gases, before acquiring the high fusion-temperature at which it could flow down into the hearth, while less calcareous slags melted sooner and ran down out of the range of action of the products of combustion.

The cinder, moreover, exercises a deterrent action on the iron as it drips down through the bosh, and by delaying its passage longer, as well as by direct contact, heats the iron nearly to its own temperature, a process which is completed as

the metal passes through the layer of slag on top of the iron in the hearth.

The cinder requires not only to be heated up to its temperature of fusion, but far enough beyond this point to give it sufficient fluidity and consequent activity to remove the sulphur coming from the coke, and permit the dissolved oxide of iron to separate out.

So long as sufficient heat is produced in the hearth to impart to the cinder the temperature necessary to give this fluidity, the iron oxide is reduced and separates out; the cinder remains bright; and silicon can be reduced and can stay in the iron, making it gray. But when the temperature required is so high, that sufficient heat for this purpose is not furnished in the hearth, the cinder becomes too thick and viscous to permit the operations mentioned; the oxide of iron remaining in it makes it black, and, acting as a powerful oxidizer, prevents silicon from going into the iron.

This condition may arise in any one of three ways: (1) by an increase in the lime-content of the slag, raising its fusion-temperature; (2) by a reduction in the quantity of available heat, due to decreased temperature of the blast or increase of moisture; or (3) by a slip, bringing down into the hearth a quantity of improperly digested material.

It thus becomes evident that the temperature necessary, not only to melt the cinder, but to make it sufficiently fluid to perform its functions properly, is the "critical temperature," since the slag and iron must be brought to this temperature, and the final reduction of the ore must be performed above it (and, most probably, other reactions). What may for convenience be called the free-running temperature of the cinder is therefore taken in this paper as the critical temperature.

Facts of Practice Explained by the Critical Temperature.

One of these is the fact that furnaces working on rich ores do not commonly show the low fuel-consumption, as compared with those working on siliceous ores, which might be expected in view of the large quantity of heat required to melt the slag. The explanation seems to be that, in smelting the richer ores, the much smaller slag-volume available for carrying off sulphur, requires a much more calcareous slag, and therefore a higher

critical temperature, which reduces the available heat per pound of fuel enough to offset largely the advantage of having less slag to melt.

The extremely low fuel-consumption of charcoal-furnaces furnishes an illustration of the opposite kind. Having practically no sulphur in the fuel to contend with, they can run on a very siliceous and fusible cinder, so that their critical temperature is several hundred degrees lower than that of coke-furnaces smelting the same ore,—which largely increases the amount of available heat.

The fuel-consumption of furnaces making ferromanganese is, on the other hand, out of all proportion to that of iron-furnaces, in view of the fact that the heat required for the reduction of MnO_2 is only 25 per cent. more than for that of F_2O_3; but this again becomes explicable when we consider the temperature necessary in the two cases, which, though not definitely known, is known to be much higher for manganese than for iron. In the case of iron, nearly all the reduction is effected before the charge reaches the critical temperature; but with manganese this is far from being the case. The quantity of "available heat" required is therefore much higher, as well as the temperature of its application, and the fuel-consumption per pound of manganese is therefore much greater.

Similarly, the fuel-consumption in producing iron containing 3.5 per cent. of silicon is probably at least 20 per cent. greater than that required for 1.5-per cent. silicon iron, though the difference in the heat actually required for its reduction is only 7 per cent. But the silicon cannot be reduced at all except at high temperatures; and the critical temperature is therefore raised, as well as the quantity of heat required above it, so that the fuel-consumption is augmented in correspondingly higher ratio.

It is interesting, in this connection, to consider why, in order to make high-silicon iron with a reasonable fuel-expenditure, a small hearth is necessary. The reason probably is that, since the necessary high temperature cannot be secured by the use of calcareous slag (because such a slag does not allow the silica to leave it and be reduced to silicon) it can only be secured by a longer exposure of the charge to the products of combustion, and for this purpose the currents of both gas and dripping iron

must be of smaller cross-section, thereby virtually lengthening them and increasing the number and duration of the contacts of the dripping iron with the incandescent fuel,—the condition most favorable to the reduction of silicon and its absorption by the iron.

If the claim here made for the existence and position of a "critical" temperature be admitted, it follows that the attainable economy of fuel is subject to a double limitation: (1) by the total development of heat produced in the furnace per pound of fuel; and (2) by the proportion of this heat available above the critical temperature.

A legitimate corollary to this proposition is, that the work done in the process may be divided into two parts, that done below the critical temperature and that done above it, corresponding approximately to the work done above the zone of fusion and that done below it, or, roughly, to that done in the shaft of the furnace and that done in the bosh and hearth. We may for convenience call these respectively, the preliminary and the final work. The total heat introduced into and developed in the furnace, being H_t, and the part expended in the bosh and hearth in the final work, being H_a (the "available" heat), the heat necessary for the performance of the preliminary work is $H_t - H_a$.

From the investigations of Bell and others, we know with considerable accuracy the total quantity of heat required for the production of a unit-weight of pig-iron; and from the diagrams herewith given we can determine approximately the proportion of this which must be applied above the critical temperature. In view of the preceding discussion, it is apparent that there must be a reasonably definite ratio between these two quantities, or between the latter and their difference—in other words, between H_a and $(H_t - H_a)$.

This can be put in the form of an equation which will help to make the matter clear.

If we call the total heat required to produce a unit of iron R_t, and the fuel required per unit of iron (calculated on this basis) n_1 (H_t being, as before stated, the total heat developed in the furnace by the unit of fuel), we have

$$\frac{R_t}{H_t} = n_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (A),$$

or $R_t = n_1 H_t$, the equation, both sides of which were so magnificently and completely analyzed by Bell.

If, however, we denote, by R_a, the heat required; above the critical temperature, per unit of iron produced, H_a being the available heat and n_2 the fuel-consumption determined on this basis, we have

$$\frac{R_a}{H_a} = n_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (B).$$

Both A and B must be satisfied, if the process is to be complete.

If we should increase the degree of oxidation of the fuel, and thus increase H_t, without affecting H_a, we would effect no fuel-economy, since we should do the preliminary work upon a larger quantity of ore than the available heat could take care of in the bosh. The furnace would consequently become cold, and an increased quantity of fuel would have to be used to make good the deficiency in available heat.

If, on the other hand, we increased the available heat, H_a, without increasing the total heat, H_t, we should either change the grade of the iron enough to absorb the heat-excess, or drive the heat up to the higher zones of the furnace, with those disastrous results which furnace-men know under the caption "too hot and sticking." But, no fuel would be saved, because no more heat being produced for the preliminary work, no increase in the quantity of ore prepared for final reduction could take place, hence no increase of output for the same fuel.

It is thus seen that it is necessary to increase the two quantities of heat in the same ratio if any economy is to be achieved. If the maximum ratio of CO_2 to CO is fixed, as claimed by Bell, then this ratio is a subject of great importance, and exercises a controlling influence on the possible economy.

Acting on this hypothesis, Bell himself carried out many experiments, as others have done since.

Mr. Bell reached, for Cleveland ores, the conclusion, which he was strongly inclined to apply to all conditions, that the maximum ratio of CO_2 to CO was 1:2. Others have shown that, on other ores, a reducing action exists at very much higher ratios than this. The most complete of these investi-

gations known to me is that of Baur & Glaessner,[6] which would have been of the highest practical value, if they had not conducted their investigations upon magnetic oxide, Fe_3O_4, under the erroneous belief that ferric oxide, Fe_2O_3, had to pass through that stage in the process of reduction to FeO.

They show clearly, however, that there is, at a temperature of 650° C., a reducing action, even on magnetic oxide, when the ratio of CO_2 to CO is 2 : 1.

The truth appears to be, that, under present conditions, the ratio of the oxides of carbon in the gas is a result, not a cause; that a certain quantity of oxygen is introduced into the furnace with the ore and the CO_2 in the flux, and that the quantity of this, in proportion to the quantity of CO formed at the tuyeres, has the primary influence on the composition of the gas. It would have the sole influence, except for the solvent action of CO_2 on coke at temperatures prevailing in the shaft of the furnace—the extent of this action being controlled by the relative quantities and conditions of the ore and fuel charged, and by the temperature at and near the top.

The amount of CO formed at the tuyeres is, however, directly dependent upon the requirements for available heat in the hearth and bosh; and the ratio to this of the oxygen brought in at the top is practically the ratio of the ore to the fuel, therefore the quantity of CO_2 in the gas is dependent upon this latter ratio. The former does *not* control the latter. In other words, as much fuel is burnt as is required to produce the available heat necessary; and to the CO formed by this combustion is added the oxygen derived from the charge. This determines primarily the ratio of the two carbon-gases; but the result is modified by the solvent action of CO_2 on coke. Within the limits of usual practice, the gas-ratio may be whatever is determined by the efficiency of the lower part of the furnace, and does not in fact constitute any present barrier to fuel-economy, the problem of which usually becomes simply a question of the quantity of available heat to be obtained per unit-weight of carbon.

This is strikingly shown by Mr. Gayley's results in the paper

[6] "Ueber die Einwirkung von Kohlenstoff, Kohlenoxyd und Kohlensäure auf das Eisen und seine Oxyde." *Stahl und Eisen*, May 1, 1903.

above quoted. As soon as he had increased the heat available at the bottom of the furnace, the burden was increased, and the increased oxygen in the charge at once oxidized the gases to a higher ratio of CO_2 to CO.

With every record of exceptional work in furnace-economy the same thing is shown: the "limiting ratio" of 1 : 2 has not stood in the way in the least, when the other conditions were made right.

There is, however, little doubt that a limitation in this direction would make itself increasingly felt, if the economy and the ratio of CO_2 to CO were increased indefinitely, for the reason that the gases in their ascent are exposed alternately to layers of ore and flux, which tend to oxidize them, increasing the CO_2, and to layers of fuel, which tend to deoxidize them, increasing the proportion of CO. The fact that sometimes one and sometimes the other of these materials has the final effect on the top-gas is the principal reason for its known rapidity of variation in composition.

There seems, however, to be no reasonable doubt that, at present, our limitation is due to the lack of heat available above the critical temperature, and that only after we have succeeded in increasing the amount of this heat obtainable from one pound of fuel, need we consider as urgent the necessity for a means of oxidizing more completely the top-gases.

When this time does come, one of the simplest and most easily applicable measures for securing increased oxidation of the carbon in the top-gases will be to calcine the limestone, which, including the saving of heat required for driving off the CO_2, at a ratio of CO_2 to CO of 1 : 1 and with 1 lb. of limestone charged per pound of coke, would effect an economy of about 1,300 B.t.u. in 7,750, or about 17 per cent.

I am well aware that it has often before been proposed to burn the limestone before charging it, and that it has been tried, with unsatisfactory results. The reason is, as I have explained before, that this only increased the total heat without increasing the available heat, when the available heat was already too small in proportion to the total. If, by increasing the available heat to such an extent that the development of total heat under present conditions would be unable to kee

step with it any longer, the opposite deficiency were produced, then a gain by this means would become probable.

The difficulties of such a step would probably be much smaller than might at first be thought, the kilns simply replacing the bins now generally used, and being fired with furnace-gas.

The principal means of obtaining an increased development of available heat, of course, is by heating the blast; but, as is clearly shown by the slope of the curves in Fig. 2, drying it is a good second.

The limitations of the use of hot blast form a subject too extensive and too complicated for discussion in this paper. It seems that nearly all furnaces can be divided into two classes: those which need higher heat, and, owing to physical limitations, cannot get it; and those which can get a higher heat than they can use. It is likely, however, that with increasing knowledge and increasing slag-volumes to melt (owing to the use of leaner ores), the second class will gradually diminish.

It is certain that heating the blast within the limits allowed by the physical limitations and the working of the furnace is the simplest and cheapest means so far available for increasing the supply of available heat; and when a limit has been set by the furnace at a certain blast-temperature under winter (dry) conditions, then another limit considerably higher may be set for summer (moist) conditions, from the diagrams given above.

It is no reflection on the value of Mr. Gayley's invention to say that a large part of the saving he effected was due to the increased heating of the blast, which he was able to obtain as a secondary advantage. Had he been able to increase the blast-temperature from 720° to 1,000°, still using moist blast, he would have obtained about the same fuel-economy, though the gain from regularity of running would not have been so great. (In this connection, however, it is well to point out that the percentage of variation in available heat and fuel-consumption for a given quantity of moisture is smaller, as the temperature of the blast is greater.)

The partial proof of this statement is contained in the records achieved at some other furnaces which exceeded the performance described by Mr. Gayley, exceptional as that is, by

the use of very hot blast. That this is possible is plainly shown by the diagrams.

It seems proper to add, also, that this saving will only average, for the year, about half that shown, since the change was made at the period of highest moisture, and the lower moisture of the dry blast about corresponds with that of winter.

With the exception of the great gain in regularity, I think it may fairly be said that those plants which have at command a constant blast-temperature 300° higher than their winter-requirements, can, by careful attention to their heats in relation to the humidity, achieve almost the same degree of economy as can be obtained by drying the blast.

Some of the best furnace-men are, as mentioned above, actually using temperatures 100° to 200° higher in summer than in winter, and at these plants the variation in fuel-consumption is insignificant, as compared with those where an approximately constant blast-temperature is used.

As furnace-work improves, and the methods of using the higher blast-temperatures without ill-effects are perfected, this limitation to the application of Mr. Gayley's improvement will become continually less important.

For the great number of furnaces which use as high a temperature as they can reasonably expect to obtain, the only hope of increased fuel-economy now open is in the application of the dry blast.

The Outlook for Coal-Mining in Alaska.*

BY ALFRED H. BROOKS, WASHINGTON, D. C.

(Washington Meeting, May, 1905.)

Introduction.

Less than a decade ago the consumption of coal in Alaska was practically limited to the salmon canneries and the few lode-mines and settlements along the Pacific coast of the Territory. The sparse population of the interior depended on the forests, that of the shores of Bering sea and the Arctic ocean on driftwood for fuel. All this has changed. The thousands, who have sought and mined gold on the Seward peninsula since 1898, have much impoverished the long-accumulated supply of driftwood, and at the same time the constantly increasing demand for fuel, on the part of the placer-camps and steamers, has resulted in heavy inroads being made on the accessible timber of the Yukon and its tributaries.

While, on the one hand, the immediately available store of wood has decreased, on the other, the consumption of fuel because of the rapid expansion of the mining and fishery industries, and the attendant growth of population has much increased. Alaska, therefore, offers a constantly growing market for coal and other fuels. As the local coal-production has been insignificant, the demand has been met by importations from Washington, British Columbia, and even from Pennsylvania and Australia.

Fuel-Consumption.

Mr. D. H. Jarvis, Collector for Alaska, has kept systematic records of the trade of the Territory since 1903. The statistics of the coal-importations of the past two years are shown in Table I. If data were available for a longer period of years, the increase of coal-importations would be much more striking.

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* Published by permission of the Director of U S. Geological Survey. In the compilation of this paper the writer has made extensive use of the reports of Messrs. Arthur J. Collier and G. C. Martin, to which reference will be made.

TABLE I.—*Shipments of Coal to Alaska.*

	12 Months Ending June 30, 1903.		12 Months Ending June 30, 1904		12 Months Ending December 31, 1904.	
	Tons	Value.	Tons.	Value.	Tons	Value.
Domestic	56,104	$256,117	42,096	$195,991	33,136	$171,511
Foreign (chiefly British Columbia)	54,072	216,089	72,000(a)	288,000(a)	90,000(a)	360,000(a)
Total	110,176	$472,206	114,096	$483,991	123,136	$531,511

(a) The figures for foreign coal in 1904 are only approximate.

Coal carried to Alaska by steamers as fuel for the return voyage, which amounts to many thousands of tons, is not included in this statement. The increase in the consumption of coal has been met by shipments from British Columbia, for it will be noted that there has been an actual decrease in the amount of coal sent to the Territory from the United States.

It is estimated that a little less than 50 per cent. of the coal is shipped to the Pacific coastal region. Since very little coal is used in the interior, most of the balance supplies the placer-mining camp in the Seward peninsula. Estimates of the cost of coal per ton in different parts of the Territory in 1904 are:—Southeastern Alaska, $8 @ $15; Valdes, $10; southwestern Alaska, $10 @ $12; Dutch Harbor, $11; Nome, $15 @ $25; north shore Seward peninsula, $30, and Yukon river, $15 @ $20.

These prices are only approximate, and are subject to a great fluctuation. Thus at Nome, during the closed season, coal often sells at $30 @ $40 a ton, and on the north side of the peninsula lignitic coals of low grade from a local source found a ready market at $40 a ton during the winter months, in competition, however, with Wellington coal at $83 per ton.

Table II. illustrates the increased consumption of petroleum in the Territory. This is largely used to replace coal, for the importations of illuminating oil, amounting to nearly $100,000 annually, are not included. Here, as in the case of coal, the cost to consumers is at least double these values.

Attention has been called to the inroads on the forests of the Yukon made for steamboat-fuel, and a similar depletion of the accessible wood-supply is noticeable in every mining-camp in the interior. Though much of this cutting is for lumber, yet that for fuel is also large. While there is no immediate

TABLE II.—*Shipments of Petroleum to Alaska.*

	12 Months Ending June 30, 1903.		12 Months Ending June, 1904.		12 Months Ending December 31, 1904.	
	Gallons.	Value.	Gallons.	Value	Gallons.	Value.
Crude petroleum.	861,000	$28,390	2,016,400	$71,823	2,016,430	$69,426
Naphthas, etc......	270,505	46,017	316,434	61,868	338,281	67,718
Total..	1,131,505	$74,407	2,332,834	$133,691	2,354,711	$137,144

danger of a timber-famine, yet, as much of the forest can be made available only by the construction of roads, the price of cord-wood will probably have an upward tendency. The heavily forested areas along the southern coast are also difficult of access, except when actually on tide-water; moreover, the humidity of the climate makes the wood less suitable for fuel than that of the interior, and it is but little used. Most of the Seward peninsula is treeless, and, up to the present time, the miners have depended on the driftwood which is now practically exhausted. Though no statistics are available, yet there can be no doubt that thousands of cords of wood are consumed annually in the Yukon basin at a cost ranging from $7 @ $15 a cord, in competition with imported coal at $15 @ $20 a ton.

On the basis of these figures it is estimated that the coal shipped to Alaska is costing the consumer more than $1,500,000 annually. Moreover, the return fuel used by steamers plying in the Alaskan trade represents an additional consumption of many thousands of tons. The annual consumption of petroleum and cordwood of the Territory is represented by an additional cost of at least $500,000. It is fair to assume, then, that the total annual outlay for fuel by Alaskans exceeds $2,000,000. These facts make it pertinent to inquire the quantity, quality and distribution of Alaska's fuel-resources, and to discuss their availability for supplying the local market.

The distribution and value of the timber will not here be considered except to say that heavy forests are limited to a part of the Pacific slope of Alaska, and that, unless steps are taken to preserve the comparatively sparse growth in the interior, the day will come when a timber-famine must be expected. This is specially true because of the forest-fires in the semi-arid regions of the Yukon basin. Petroleum and peat deserve mention as possible sources of fuel, but as petroleum has not

yet been found in commercial quantities, and as no attempt has been made to utilize the extensive peat-deposits, these are not now economic factors. The most hopeful possibilities of developing a local fuel-supply, centers in the coal-resources which are now almost undeveloped. Though there are known to be extensive coal-fields in Alaska, mining of coal in 1904 was confined to the exploitation of lignitic seams at three or four widely separated localities, and the entire product probably did not exceed 2,000 tons.

The Coal-Bearing Rocks.

The accompanying map (Fig. 1) shows the known coal-bearing rocks of Alaska, and indicates their very wide distribution. The shaded areas are intended to cover only such regions in which there are known to be coal-seams believed to be of present or future importance, and does not by any means include all of the districts in which coal-bearing horizons have been found. This limitation of shaded areas, and the fact that reconnaissance-surveys have been made of only about one-fifth of the Territory, makes it probable that the coal-fields are much larger than here indicated. As it happens that the coal-fields now known in Alaska are about equal in area to those of Pennsylvania, this better-known district can be conveniently used as a standard of comparison. Their relative size is shown by a sketch of Pennsylvania of the same scale, which appears on the map as an insert. Both provinces include about 16,000 sq. miles of coal-bearing rocks, but, while the limits of the Pennsylvania fields are fairly well known, the Alaskan fields are barely explored. It is most probable that the coal-fields of Alaska will be found to have many times the area of those of Pennsylvania. It must be admitted, however, that, though there are some very high-grade coals in the Territory, yet much the larger part of it is probably of a lignitic character. Moreover, much of the Alaskan coal-land is so inaccessible that it is hardly an asset of immediate importance, and can for the present be regarded only as a part of the world's ultimate fuel-reserve.

Though much remains to be learned of the geology of the coals in this northern province, yet coal-seams which promise to be of commercial importance are known to occur in five of

the large divisions of the geologic column. Each of these divisions may carry many different seams, as some are already known to do. Besides these seams, which are probably exploitable, other coal-bearing horizons have been found that are believed to be of no commercial importance. In the Table III. the stratigraphy of Alaskan coal-bearing horizons is briefly summarized.

TABLE III.—*Stratigraphic Position of Coals.*

System	Series	Character of Coal	Distribution
Tertiary	Eocene.	Chiefly lignitic.	Identified in southeastern Alaska, in Cook Inlet region, Yukon basin and northern Alaska.
Tertiary	Undetermined.	Bituminous and semi-anthracitic, with some natural coke.	Identified only in Controller Bay region. Coals in Matanuska valley may be of this horizon.
Cretaceous	Upper Cretaceous.	Bituminous and lignitic coals.	Lower Yukon, and may occur in islands of southeastern Alaska.
Jurassic...	Upper Jurassic. (?)	Bituminous.	Extensive areas in Cape Lisburne region. Probably occurs elsewhere in northern Alaska.
Carboniferous. (?)	Permian. (?)	Bituminous.	Nation river, tributary of Yukon. Some small seams of this horizon also occur near head of White river.
Carboniferous.....	Mississippian.	Bituminous.	Near Cape Lewis, 20 miles south of Cape Lisburne.

The oldest coal of the Territory, belonging to the Mississippian subdivision of the Carboniferous (Lower Carboniferous), has been recently found by Mr. Arthur J. Collier,[1] of the United States Geological Survey, along the Arctic coast south of Cape Lisburne. Mr. A. G. Maddren[2] was the first to suggest a Carboniferous age for these coals. This discovery of Carboniferous coal on the Pacific slope is not only of scientific import, but may have far-reaching economic significance. It should be noted, however, that this terrane is much older than those of

[1] Report on Progress of Investigations of Mineral Resources of Alaska in 1904, *Bulletin No.* 259, *U. S. Geological Survey* (1905).

[2] A Reconnaissance in Northern Alaska, by F. C. Schrader, *Professional Paper No.* 20, *U. S. Geological Survey*, pp. 113–114 (1904).

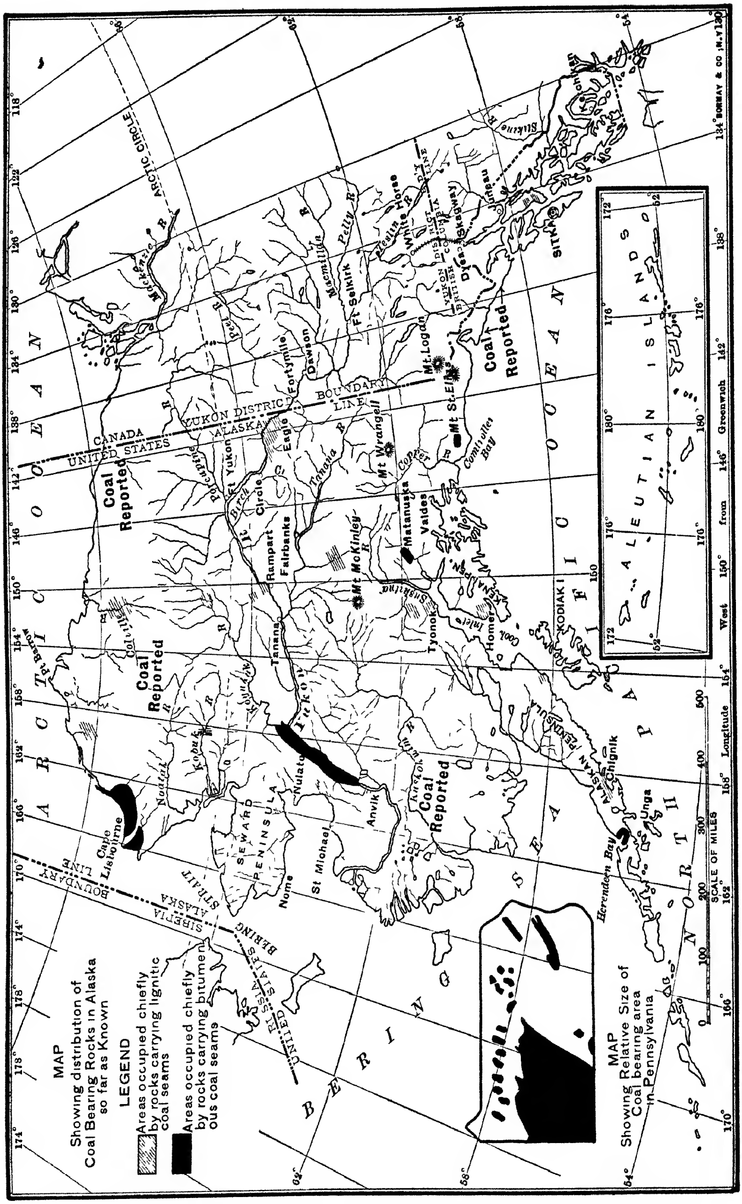

FIG. 1.—MAP OF ALASKA SHOWING THE DISTRIBUTION OF THE COAL-BEARING ROCKS SO FAR AS KNOWN.

the coal-measures of the eastern United States. The coal occurs in a series of shales and slates, with some limestones, probably 1,000 ft. thick, which is thrown up into broad, open folds. No coal-seams of lower Carboniferous are known elsewhere in Alaska.

Coal has been found in association with Permian rocks in only two localities in Alaska and neither give promise of having value. A little mining has been done on a coal-seam outcropping on the Nation river, a northerly tributary of the Yukon river, 52 miles below the Boundary. Mr. Collier[3] describes the rocks, in immediate association with this coal, as conglomerates and shale, while close at hand are limestones carrying a Permian marine fauna. The folding, which is very complex, is accompanied by faulting, and the relation of the two series has not been established. Near the International Boundary and in the Upper White River basin some small coal-seams[4] have been found interbedded with semi-crystalline limestones carrying a Permian fauna.

The Jurassic is the next younger coal-bearing horizon, but though this horizon is widely distributed in the Territory, only near Cape Lisburne has it yielded workable coal-seams. Coals of Mesozoic age have been reported in the Copper River basin.[5] The coal[6] at Cape Lisburne has long been known, but it is only since the recent investigations by Mr. Arthur J. Collier[7] that definite information regarding it has been available. The rocks associated with the coal are shales, sandstones and conglomerates, aggregating a thickness of from 10,000 to 15,000 feet. These rocks are folded, the dips ranging from 0° to 60°.

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[3] Collier, Arthur J., The Coal-Resources of the Yukon, Alaska, *Bulletin No.* 218, *U. S. Geological Survey*, pp. 33–36 (1903).

[4] Brooks, Alfred H., A Reconnaissance from Pyramid Harbor to Eagle City, 21*st Annual Report of the U. S. Geological Survey*, pt. 2, p. 382 (1900).

[5] The Mineral Resources of the Mt. Wrangell District, by W. C. Mendenhall and F. C. Schrader, *Professional Paper No.* 15, *U. S. Geological Survey*, pp 67–68 (1903).

[6] Brooks, Alfred H., Coal-Resources of Alaska, 22*d Annual Report U. S. Geological Survey*, pt. 3, pp. 561–562 (1903) Also, Schrader, F. C., A Reconnaissance in Northern Alaska, *Professional Paper No.* 20, *U. S. Geological Survey*, pp. 111–114 (1904).

[7] A preliminary statement of Mr. Collier's results are contained in Report on Progress of Investigation of Mineral Resources of Alaska in 1904, *Bulletin No.* 259, *U. S. Geological Survey*, (1905).

Coal-bearing beds of upper Cretaceous[8] age have been found on the Lower Yukon, from the mouth of the Koyukuk nearly down to the head of the delta, a distance of about 200 miles, and with an unknown width. The exposed section, including shales, sandstones and conglomerates, probably does not exceed 2,000 ft., and locally the beds are considerably disturbed.

Upper Cretaceous beds have recently been found near Chignik, on the Alaska peninsula, by Messrs. T. W. Stanton and R. W. Stone of the U. S. Geological Survey; and it is possible that the coals of that vicinity are of the same age. A similar interpretation might be placed on what is known of the coal at Herendeen bay, 100 miles to the southwest. Coals, occurring in sandstones, shales and conglomerates of the upper Cretaceous age, have also been found[9] on Kuiu island in Southeastern Alaska, but are not known to be of commercial value.

Alaska yields two essentially distinct classes of Tertiary coals: first, the lignites of the widely distributed Kenai horizon of Eocene age; and second, the high-grade bituminous and semi-anthracite coals, which so far have been found only in the Controller Bay region of the Pacific coast, which may also be of Eocene age. Coals of similar character, which may be of the same age, are reported to occur in the Matanuska valley north of Cook inlet.

The Kenai series is the most widely distributed terrane of Alaska and has been identified in all parts of the Territory. It usually occurs in comparatively small basins, but in the Kenai peninsula, in parts of the Yukon basin, and probably in northern Alaska, it forms the country-rocks over considerable areas. Typically, it is made up of shales, sandstones and conglomerates, in some places entirely undisturbed; in others, intensely deformed.

The Controller Bay coals, which have recently attracted so much attention, because of their high fuel-value and of the great thickness of the seams, have been the subject of investigation by Dr. G. C. Martin[10] of the U. S. Geological Survey,

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[8] Collier, Arthur J., The Coal-Resources of the Yukon, Alaska, *Bulletin No.* 218, *U. S. Geological Survey*, pp. 19–20 and 46–60 (1903).

[9] Wright, F. E., and Wright, C. W., of the U S. Geological Survey. Unpublished results.

[10] The Petroleum-Fields of the Pacific Coast of Alaska, with an Account of the Bering River Coal-Deposits, *Bulletin of the U. S. Geological Survey*, No. 250 (1905).

who assigns them to the Tertiary, and indicates that they may possibly be of Kenai age. The coal-bearing rocks embrace several thousand feet of sandstone, shale, arkose, and volcanic ash, and are considerably folded and faulted. A similar grade of coal is reported in the Matanuska[11] valley, 200 miles to the northwest. Little is known of its stratigraphic relations, but it may be of the same horizon as that of Controller bay.

Some fibrous lignitic coals have been found in unconsolidated beds of various ages and in different parts of Alaska. As these appear to have no present or future value, they will not here be considered.

Composition and Fuel-Value of Coals.

Broadly speaking, there are three grades of Alaskan coal, semi-anthracite (coals whose composition is about half-way between bituminous and anthracite are here classed for convenience as semi-anthracite), bituminous and lignite. Semi-anthracite is known to occur in commercial quantities only at Controller bay, but has also been reported in the Matanuska valley. Bituminous coals have been found at Controller bay, in the Matanuska valley, at Herendeen bay, in the Alaska peninsula, on the Lower Yukon river, and near Cape Lisburne. The map shows that the lignitic coals have a very wide distribution, but have been mined only on Admiralty island, where all operations have ceased; at Homer, on the Kenai peninsula, at Chignik and Unga, in southwestern Alaska, at several points on the Yukon, and at one or two localities in the Seward peninsula. Though the higher grades of coal have not been found in as large areas as the lignites, yet they are sufficiently abundant to constitute a factor in the fuel-resources.

In Table IV. is summarized the available information on the composition of Alaskan coals, but for statements regarding individual seams references must be made to the reports cited.

Since the methods employed in sampling and analyzing the coals in Table IV. are by no means uniform, it is of use only for the purposes of general comparisons. One fact is plainly indicated by this table, and that is, that the Alaskan coals compare favorably in composition with those of other fields which

[11] Stone, R. W., in Report of Progress of Investigations of Mineral Resources of Alaska, in 1904, *Bulletin No.* 259, *U. S. Geological Survey*, pp. 151–187 (1905).

TABLE IV.—*Average Composition of Alaskan Coals, Together with a Comparison with Those of Other Fields.*

	Fixed Carbon.	Vol. Matter	Moisture	Ash.	Sulphur	Fuel Ratio	Calories	Notes.
	Per Cent	Per Cent.	Per Cent	Per Cent.	Per Cent.	Per Cent		
Average of 10 analyses of bituminous, etc., coals from Controller bay (Tertiary) (*a*)	78 41	15.32	1 18	5.10	1 25	5 12	8,156	Includes some coking coals
Average of 3 analyses of bituminous coals from Cape Lisburne region (Carboniferous) (*b*)	75 94	17 47	3 66	2 92	0 96	4 46	..	Non-coking
Average of 12 analyses of bituminous coals from Cape Lisburne region (Jurassic) (*b*)	46 83	38 42	9 46	5 24	0 38	1 21		Non-coking
Average of 9 bituminous coals from Yukon river (Cretaceous) (*c*)	55 89	32 05	4 69	6 97	Not given	1 74		Includes some coking coals
Average of 9 lignitic coals from Yukon river (Tertiary) (*c*)	40 82	41.11	11 89	6 20	Not given	0 99		
Average of 6 analyses of coal from Kachemak bay (Tertiary) (*d*).	30 99	40 48	19 85	8 68	0 35	0 77		
Average of 14 analyses of bituminous coal from Vancouver island, B C (*e*)	57 64	29 55	1 49	10 75	0 75	1 74		
Average of 10 analyses of bituminous coal from the State of Washington (*f*)	56 01	31.60	4 43	7 45		1 45		
Average of 12 analyses of bituminous coals from West Virginia (*g*)	63 94	27 63	2 25	6.17	1 09	2 31	7,982	
Average of 6 analyses of bituminous coals from Illinois (*g*)	42 56	35.23	7.61	12 90	3 02	1 20	6,296	
Average of 2 analyses of lignites from Texas (*g*)	23 41	36 49	30 72	9 38	0 53	0 64	4,181	
Average of 2 analyses of lignites from North Dakota (*g*)	36 55	37 91	16 06	9 47	1 32	0 96	5 153	

(*a*) Martin, G C, *Bulletin U S. Geological Survey*, No 259

(*b*) Collier, Arthur J, *Bulletin U S Geological Survey*, No 259

(*c*) Collier, Arthur J, *Bulletin U S Geological Survey*, No 218

(*d*) Stone, R W, *Bulletin U S Geological Survey*, No 259

(*e*) Robertson, W. F, *Annual Report Minister of Mines*, British Columbia for 1902, pp 261–264

NOTE.—The low moisture contents of the Vancouver Island coals suggests that the samples were dried out before being analyzed

(*f*) Smith, G. O, Coal-Fields of the Pacific Coast, 22d *Annual Report of the U S Geological Survey*, pt. 3 (1902), p 490

(*g*) Parker, E. W., Holmes, J A, and Campbell, M. R, Preliminary Report of the Operations of the Coal-Testing Plant, *Bulletin of the U S. Geological Survey*, No. 261 (1905), pp. 32–59.

have been extensively developed. So far as composition can determine their commercial value, the Alaskan coal should be able to compete with the imported coals from Washington and British Columbia. The final test must rest on actual use; and, up to the present time, there have been only a few practical tests of Alaskan coal, and even these were made under unfavorable conditions.

Of the fuel-value of the higher grades of coal of Table IV. there can be no doubt, and even the lignites may yet find their use as power producers. The results of the recent fuel-tests made at St. Louis by the U. S. Geological Survey may revolutionize the mining-industry in Alaska in making available the fuel-values of the lignites by use of gas-engines. The following is quoted from a recent publication:[12]

"Some of the lignites from undeveloped, but extensive, deposits in North Dakota and Texas, when tested in the gas-producer and gas-engine, have shown unexpectedly high power-producing qualities, such as promise large future developments in those and other States."

The Coal-Fields.

The coals of southeastern Alaska, so far as known, have little value at present, for seams thus far discovered are thin, and the coal of a lignitic character. All those which have been opened up appear to be of Tertiary age, and unless some older horizon is discovered which carries better coals, this part of Alaska can hardly be expected to produce even a local fuel-supply, unless for use in gas-engines.

Messrs. F. E. and C. W. Wright have recently found coals on Kuiu island which may be of Cretaceous age. Their economic importance remains to be proved. The largest areas of lignitic coals in this field occur on the southern part of Admiralty[13] island, where the seams vary from a few inches to several feet in thickness. Locally, the beds show much irregularity of structure, and are considerably crushed. Some attempts at coal-mining have been made at Hootznahoo inlet, on the west side of the island, and at Murder cove, near its southern extremity. Coal-seams have been reported at[14] Lituya and Yakutat bays, but nothing is known of their extent or quality. It seems possible that these may lie in an eastern extension of the Controller Bay field to be described.

The Controller Bay coal-field appears to have a promising

[12] Parker, E. W., Holmes, J. A., and Campbell, M. R., Preliminary Report on Coal-Testing Plant of the U. S. Geological Survey, *Bulletin No.* 261, *U. S. Geological Survey,* p. 17 (1905).

[13] Wright, F. E. and C. W., in Report on Progress of Investigations of Mineral Resources of Alaska, in 1904, pp. 47–69, *Bulletin No.* 259, *U. S. Geological Survey* (1905).

[14] Brooks, Alfred H., The Coal-Resources of Alaska, pt. 3, 22d *Annual Report of the U. S. Geological Survey,* p. 541 (1902).

future. According to Dr. Martin, all this field lies within 25 miles of tide-water, and includes a known area of 120 sq. miles, but as the district has been only partly surveyed, it may be considerably larger. At least a dozen workable seams are reported, ranging in thickness from 9 to 25 ft., and there is probability that detailed surveys will reveal other seams. The coals are of a semi-anthracite or bituminous character, and of high fuel-value. Some natural coke has also been found. The associated rocks are considerably folded and faulted, but there appears to be a large available coal-supply advantageously located for exploitation.

The most serious obstacle to the development of this field lies in the lack of shipping-facilities. Though the construction of a railroad to the coast would be easy, the absence of a suitable harbor makes the loading of vessels difficult. To obviate this difficulty, it has been proposed to construct a railway to some good harbor on Prince William sound. This would require at least 100 miles of track, with much expensive construction, including the bridging of the Copper river. A serious obstacle to such an enterprise is the crossing of the many glacial streams which, because of their shifting courses, are difficult to bridge. The region adjacent to this coal has been the scene of much active prospecting for oil, and the surface indications are favorable for the development of an oil-bearing district. If an oil-pool be found there would be a further incentive to the establishment of shipping-facilities. The region is well timbered and the coast is ice-free throughout the year.

A second field, in which the coal is reported to be similar to those just described, lies in the drainage-basin of the Matanuska river, about 200 miles northwest of Controller bay and about 50 miles from tide-water at Cook inlet. This region is one of the objective points of a railroad now under construction inland from the excellent harbor of Resurrection bay. Current reports indicate that the seams are of a thickness to warrant exploitation, and that the coal is of a high grade.

On the map given in Fig. 1, areas of lignite-bearing horizons are shown to be abundant in the Cook Inlet region and in Alaska peninsula; and at many localities these outcrop at or close to tide-water. While their fuel-value does not compare with the coals above described, yet their accessibility and abun

dance makes them not without commercial import, specially in view of their possible value for use in gas-engines.

The north shore of Kachemak bay is made up of lignite-bearing shales, sandstones and conglomerates[15] which are of Kenai age. Some mining has been done near Homer, on the north side of the bay. A 7-mile railroad connects the workings with the shipping-point, where a wharf has been built. This enterprise does not yet appear, however, to have been a commercial success, for in 1903 all operations were suspended. The coal occurs in seams from 2 to 7 ft. thick, and is exposed in bluffs, offering favorable opportunities for economic exploitation.

A small area of the same rocks is found on Graham bay, a few miles south of Homer, where the Russians mined coal, with the aid of convict-labor, over half a century ago, and which was, in fact, the first attempt at mining in Alaska. Some lignites, which are exposed on the west shore of Cook inlet, near Tyonok, have been mined in a small way for local use. To the north, lignites have been found at a number of localities in the Sushitna basin, but their extent and value are unknown.

Lignitic coal has been reported at various localities in the Alaska peninsula, but it has been mined only at Chignik and at Herendeen bay. At the former, a small mine was opened up about 10 years ago, and has been a small producer ever since. At Herendeen bay,[16] the coal appears to be of somewhat better grade, but so far the attempts at exploitation have been unsuccessful, it is said, because the seams are much broken. At Coal harbor on Unga island, a seam from 3 to 6 ft. thick has been developed in a small way. It appears that, though there is considerable lignitic coal in southwestern Alaska, it is only at Chignik and Unga that attempts at mining have yet met with success.

Small areas of lignitic-bearing beds, probably of Kenai age, occur in different parts of the Copper River basin.[17] Such deposits have been reported from the Chistochina, Gakona,

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[15] Stone, R. W., in Report of Progress of Investigations of Mineral Resources of Alaska in 1904, *Bulletin No.* 259, *U. S. Geological Survey*, pp. 151–171 (1905).

[16] Brooks, Alfred H., The Coal-Resources of Alaska, 22*d Annual Report of the U. S. Geological Survey*, pt. 3, p 547 (1902).

[17] Mendenhall, W. C., and Schrader, F. C., The Mineral Resources of the Mt. Wrangell District, Alaska, *Professional Paper No.* 15, *U. S. Geological Survey*, pp. 66–68 (1903).

Cheshnena, and Tazlina River basins. Some of these appear to be fair grades of lignites, and may in the future have a value for local use. A coal of a somewhat higher grade, on the authority of prospectors, occurs in the shales of Mesozoic age in the upper Chitistone River basin. This has some of the physical and chemical properties of cannel. As the thickness of the seams, and the extent of the field are unknown, its commercial value remains to be determined.

The coals of the Yukon river,[18] as has been shown, fall into two groups, first those of the lower river, of a bituminous character and of Cretaceous age, and second those of the upper river, which appear to be chiefly lignitic and are Tertiary in age. The bituminous coals of the lower river occur in a belt of Cretaceous rocks exposed along the west bank of the Yukon for about 200 miles below the mouth of the Koyukuk. There appears to be considerable irregularity in the seams which are usually less than 3 ft. thick, but the quality of the coal is good. A little mining has been done in this field, but since the introduction of petroleum-burning engines on the river-steamers, operations have practically ceased.

The lignite-bearing beds of the Yukon basin are widely distributed, but the coal-seams have been opened up in only a few localities. The seams found vary from a fraction of an inch up to 20 ft. or more in thickness, those which have been developed being from 2 to 4 ft. thick. The coal is a lignite of a somewhat higher grade than that of southwestern Alaska. Some mining has been done at Rampart and on Coal and Washington creeks, but, like the mines on the lower river, operations have ceased since the introduction of petroleum as fuel for steamers.

A coal-field lying on the head of the Cantwell river, a southerly tributary of the Tanana, appears to include more seams than any other part of the Yukon basin. A single analysis from a surface-cropping of lignite in this district proved to be of fair grade. In a section of 450 ft. of sandstones and shales, which I measured, 15 different seams were noted, with an aggregate of 125 ft. of coal and bone, of which probably about 60 ft. were a fair grade of lignite. The largest seam measured about 20 ft. at the outcrop, but this included much bone and

[18] Collier, Arthur J., The Coal-Resources of the Yukon, Alaska, *Bulletin No. 218, U. S. Geological Survey* (1903).

shale. This field, lying as it does within 100 miles of the Fairbanks placer-district, may yet become an important source of fuel. It lies on the route of a railway under construction from Resurrection bay. Lignite coal has also been found on the Dall[19] and Koyukuk[20] rivers, but is little known, and has probably only a remote value.

There are coal-bearing rocks in the region lying east and northeast of Norton bay, but the extent and value of the seams are undetermined. Some very good looking coal has been reported[21] in the basin of the Unalaklik river, and it seems fair to assume that these occur in a western extension of the Cretaceous coal-field of the Lower Yukon. Mr. Mendenhall[22] reports coal in the valleys of both the Tubutulik and Koyuk rivers which flow into Norton bay from the north. The demand for fuel at Nome will justify a careful investigation of this field, but, at present, its commercial possibilities are entirely undetermined.

There[23] are several small basins of coal-bearing rocks in the Seward peninsula, but few of commercial value, except, possibly, those just north of Norton bay already described. A coal, which is a rather low-grade lignite, has been opened up on Chicago creek, a tributary of the Kugruk, in the northern part of the Seward peninsula. The output from this little mine has found a ready local sale.

Reference has already been made to the two distinct horizons of coal found at Cape Lisburne by Mr. Collier. The carboniferous coal outcrops along the coast south of Cape Lisburne, and has been found in seams 4 and 5 ft. thick. Their topographic position is favorable for exploitation, but their areal extent is yet unknown. The coal is of a high-grade bituminous character. To the northeast of these, lies the second field of younger coals, which includes an area of at least several hun-

[19] Mendenhall, W C , A Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, *Professional Paper No.* 10, *U. S. Geological Survey*, p 49 (1902).

[20] Schrader, F. C , A Reconnaissance in Northern Alaska, *Professional Paper No.* 20, *U. S. Geological Survey*, p. 107 (1904).

[21] Brooks, Alfred H., The Coal-Resources of Alaska, p. 560, 22*d Annual Report U. S Geological Survey*, pt. 3, p. 560 (1902).

[22] Mendenhall, W C., Reconnaissances in the Cape Nome and Norton Bay Regions, Alaska, in 1900, *U. S. Geological Survey*, p. 214 (1901).

[23] Moffit, F. H., The Fairhaven Gold-Placers of the Seward Peninsula, *Bulletin No.* 247, *U. S. Geological Survey* (1905)

dred square miles which borders the coast. Coal-seams are abundant in this area and the analyses show them to be of bituminous character, but not of as high a grade as the older coals. Collier reports that there are at least 150 ft. of coal distributed through 40 or 50 seams, of which ten or more are workable.

Mining has been confined, so far, to the bluffs which face the sea, chiefly for use of whalers and revenue cutters, but some small shipments have been made to Nome. This coast is locked in the ice for all but two or three months in the year. Moreover, there is no harbor, and it would not be feasible to build wharves to withstand the ice-floes. Mr. Collier has pointed out, however, that a lagoon near Point Hope might now be utilized for small vessels, and could be dredged for larger ones. The use of this lagoon would involve the construction of from 30 to 40 miles of railroad.

The reports of explorers[24] and prospectors indicate that there are large areas of coal-bearing rocks in the Arctic slope of northern Alaska. These coals, though they will, in the time to come, play a part in the world's fuel-supply, are too remote to be of present commercial interest.

The Local Markets.

Given local transportation-facilities at reasonable cost, and the development of Alaska's coal-fields is assured; but under present conditions of shipment, the outlook for extensive operations is not hopeful. If, however, the native coal can be brought to the localities where there is a large fuel-consumption, in competition with the imported fuels, there is here a good undeveloped field for mining.

The settlements of Alaska fall into three groups determined by routes and means of transportation. The first is the Pacific coastal region, with which may be conveniently grouped Bristol bay, an arm of Bering sea, lying north of the Alaska peninsula. All of this province is accessible from tide-water throughout the year. Second, is the Yukon province, embracing the area tributary to that river and its confluent streams, having water-

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[24] Schrader, F. C., A Reconnaissance in Northern Alaska, *Professional Paper No.* 20, *U. S. Geological Survey* (1904), and Mendenhall, Walter C., A Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, *Professional Paper No.* 10 *U. S. Geological Survey* (1902).

transportation, only during the summer months. Third, is the Seward peninsula, reached by ocean vessels during the open season from June to October.

The chief industries of the Pacific province are mining and fisheries, and all the important settlements are located on tide-water. It is estimated that this part of Alaska uses from 60,000 to 70,000 tons of coal annually at a cost of from $700,000 to $800,000. In addition, the cargo of each incoming steamer is made up, in part, of coal for the return voyage. If the high-grade Alaskan coals, such as those of Controller Bay region and the Matanuska, can be delivered on ocean steamers at a reasonable cost, these will soon supplant the imported coals. The coking-coal might find a market by supplying smelters which should use the copper-ores of Prince William sound or even those of Admiralty island in southeastern Alaska.

A coaling-station for the trans-Pacific merchant-marine may yet find a place on one of the Aleutian islands which lie close to the Great Circle route from Puget sound to Yokohama. The U. S. Navy Department has already recognized the military importance of the group by locating a naval-base at Kiska island, which has a central position in the archipelago. This naval-station will create a demand for high-grade fuel.

The outlook for lignitic coals of this province is less hopeful, for a market could be found only by underselling the imported coals of higher fuel-value. There appears, however, to be no reason for believing that mining along the Pacific coast of Alaska should cost much more than in the States, and the lignites near tide-water may yet be able to compete with the imported coals. In fact, the lignitic coals on Cook inlet are even now being mined, in a small way, for local use. The many salmon canneries on Bristol bay are large coal consumers, but it is doubtful whether the Alaskan coal can compete in this field with the imported. At present, this industry is supplied by fuel carried in the vessels, the return cargoes of which, are made up of canned salmon. If considerable deposits of good lignitic coal be found in the Alaska peninsula, which is by no means impossible, they could probably supply the Bristol Bay demand in competition with outside coals.

It is estimated that about the same quantity of fuel is used in the Seward peninsula as in the Pacific coastal province, but at

much higher cost to the consumer. At present, this fuel is all brought a distance of nearly 3,000 miles, either from Puget sound or from British Columbia. There are three possible local sources of coal: (1) the Alaska peninsula; (2) the region bordering Norton sound, and (3) near Cape Lisburne.

The coal-fields of Alaska peninsula are not very promising, but that of Herendeen bay may yet yield a fuel-supply, though its development thus far has been anything but a commercial success. This bay is accessible throughout the year, has a good harbor, and is about 700 miles distant from Nome. In any event, plans for developing the Norton Bay and Cape Lisburne fields should take into account the possibility of coming into competition with the Alaska Peninsula coals. The commercial value of the coals in the Norton Sound region has still to be proven, for, up to the present time, only small areas of lignitic coals have been found, but it is not impossible that somewhat higher grade coals may here occur, such as those of the Lower Yukon, and even the lignitic coals may yet have their value in the Nome market. The profit in mining these lower-grade coals must be found at a selling-price which will be determined by the relative fuel-value of the lignites and the imported bituminous coals. Though lignitic coal has been mined at a profit on Chicago creek in the Seward peninsula for two years, it must be remembered that this fuel hardly comes in competition with imported coals.

The Cape Lisburne fields, 200 miles north of the Seward peninsula, contains the nearest coal of high grade, but attempts to supply the Nome market from this source have met with but scant success. It appears, however, as if the possibilities in this direction had not yet been exhausted, for these coals compare well in fuel-values with any now brought to Nome, and workable seams are exposed close to the coast. As already indicated the greatest obstacles are the shortness of the shipping-season, and the absence of harbors. The immediate commercial possibilities of this field would thus appear to be limited to mining for shipment on small vessels which could enter the lagoons. A careful survey of the local conditions must be made to determine whether or not a larger enterprise could succeed, but of the quantity and quality of the coal there can be no doubt.

The high price of coal in the Nome market ($18 @ $25 per

ton) makes the development of a local field appear an attractive business-proposition. It must be borne in mind, however, that a considerable percentage of this cost of coal is represented by the lighterage charges at Nome. It does not seem likely that any local field can be developed which will escape the lighterage charges, which are variously estimated at $2.50 @ $5 per ton. The high wages, from $5 to $6 a day, which prevail in this region, is another factor which must be taken into account.

It cannot be too often urged, that any enterprise which undertakes a search for coal to supply the Nome market should establish both the quality and quantity of coal before making a large investment.

In the Yukon province, wood is the customary fuel. Up to two years ago, nearly all the score or more of river-steamers, which carried on the summer transportation business, burned wood, but a few thousand tons of coal were annually imported or mined along the Yukon river. Since the introduction of petroleum-burning engines on the steamers, all coal-mining has ceased, but some coal is still imported. It has been shown that on the Lower Yukon there are some bituminous coals of fair grade. These occur in commercial seams, and it would appear that they ought to afford a cheaper fuel than petroleum, which is brought more than 3,000 miles. Though there is considerable timber in the Yukon basin, only a small part of it is accessible to the waterways, and this is rapidly being cut. The time is not far distant when fuel will either have to be brought into the country, or roads be constructed which shall make other timber accessible. The rapid increase of placer-mining operations, specially those which make use of steam-power, will increase the demand for fuel. If the local coals, even if of a lignitic character, can be transported at reasonable cost to the mining-centers, they will undoubtedly find a large market. The introduction of gas-engines, to which the lignites are so well adapted, may yet reduce, materially, the cost of placer-mining operations. It appears that the lignitic coal on Washington creek on the upper river may eventually find a local market for mining-purposes. The coal near Rampart should supply the placer-camps of the immediate region. If the railroad be extended through the Cantwell River coal-field from the coast, it will probably supply Fairbanks with fuel from this local source.

Geological Mine-Maps and Sections.

BY D W. BRUNTON, DENVER, COLORADO.

(British Columbia Meeting, July, 1905)

THE maps of our large mines are usually prepared with the greatest care; and it is somewhat singular that, in comparison with the great amount of time and money spent in surveying and platting, so little actual use is made of them. Almost the only purpose for which a completed survey-map is afterwards consulted, is the determination of the relative position of the different workings to each other, and to the boundary-lines of the property.

After the completion of such a map, it should be made the beginning of another, and in most cases a far more important undertaking, namely, its utilization as a starting-point for a complete inventory of the company's underground possessions. The ordinary mine-survey map, being nothing but a record of what has been done, is, in one sense, only ancient history. To increase its value, such additions should be made as will render it a complete statement of the amount and value of ore in sight at any particular time, and a guide for future development. Comparatively little extra labor is involved in this undertaking, since the larger and most expensive part of the work has already been completed when the mine has been surveyed and mapped. The necessary additions consist in working out and platting on the maps, the geology of the mine as exposed in the workings, in such a manner that the geological survey may be of daily use in the development and operation of the mine.

The first step towards the production of a geological map consists in tracing individual level-sheets from the general or composite map. The area to be included, outside of the property in question, will depend very much on local conditions; but, for geological, legal and commercial reasons, it should be extended as far as reasonably practicable. The scale to be

adopted likewise depends on local conditions and individual preference; but experience has shown 40 ft. to the inch to be a very convenient scale. Where the area to be included would necessitate a map of more than 30 in. wide by 36 in. long, it is better to divide it into different sections, the maps of which can then often be made somewhat smaller, say, 24 by 30 in., which is a very convenient size.

The individual level-sheets should be very carefully made, so as to register perfectly, and should be perforated (preferably on the left-hand side) to pass over three pairs of arch-files, secured to the left-hand side of a very thin paneled frame about 1 in. larger, all round, than the maps, somewhat after the manner of an arch-file bill-holder. The vertical stems on the front of the files hold the individual level-sheets in position so that they register perfectly with each other, and the swinging-hooks at the top permit the removal of any sheet for additions or corrections.

To keep the sheets from curling, a heavy paste-board cover should be fitted over the top; and, instead of perforating it for the front uprights, it will be found better to cut longitudinal slots to take both front and back uprights, so that the cover can be readily lifted off whenever the sheets are to be used.

Where a district of considerable area has to be covered, and a large number of section-books are required, they are most conveniently kept in a horizontal position in a case provided with runners, the same as drawers, and, in order to economize space, special arches 1.5 in. lower than the regular pattern can be readily obtained from the factory.

After the individual sheet-maps are traced, the next step is to transfer them by means of carbon-paper into pocket note-books. Any size may be adopted for this work; but in practice it is found that a large book (say 8 by 10 in.), permitting comparisons over a considerable area, is most convenient. In some cases, where the geology is reasonably simple, a convenient plan is to take very light-colored blueprints of the individual level-sheets directly into the mine. These can be folded up into a convenient size for carrying in the pocket, and, unless the geology is extraordinarily complicated, will answer every purpose. In taking the geology of different levels, the greatest care must be observed to record the facts exactly as

they occur in the ground, without bias for or against any previously adopted theory. In old workings the openings must be examined with the greatest care, in order to determine exactly the boundaries of the ore-body, and the strike and dip of the spurs and intersecting veins, as well as of all faults, slips, water-courses, etc.

After the geological records have been thus brought up to date, the geology of new workings is very much more easily determined. In fact, it will usually be found that the foremen, shift-bosses, and even the common miners will take such an interest in the work that every change of rock or ore-values, and every slip or fault will be pointed out to the geologist by the men, instead of his having to hunt for them, as he has had to do in the older workings.

It has always been found that, when the work is recorded in exact accordance with observed facts, the theories will take care of themselves, and little or no difficulty will be experienced in interpreting the facts when vertical sections are made from the horizontal sheets. These are to be platted directly from the horizontal level-sheets, and, if the work has been carefully and correctly done, the result will be a set of vertical geological sections of the greatest value, not only in checking up the work on the horizontal sections, but also in furnishing the best possible basis for measuring the rate of development and ore-extraction, as well as determining at any time the amount and value of ore in sight.

Both horizontal and vertical sections may be used for the recording of samples, the better plan being to encumber the map only with the number of the sample; the description of the ore, the width sampled, etc., together with the assays, being entered in a separate note-book.

The entire system will be readily understood upon a study of the accompanying illustrations, which, as engraved, differ from the originals in three respects: (1) they have been reduced in scale; (2) they are bound in place, so that the several sheets are not removable, as they would be in practice; and (3) the colors which are most convenient and effective in practice are here replaced with conventional *hachure* in black.

I would here say, that, in my judgment, every company operating large mines would find it advantageous to employ, as a

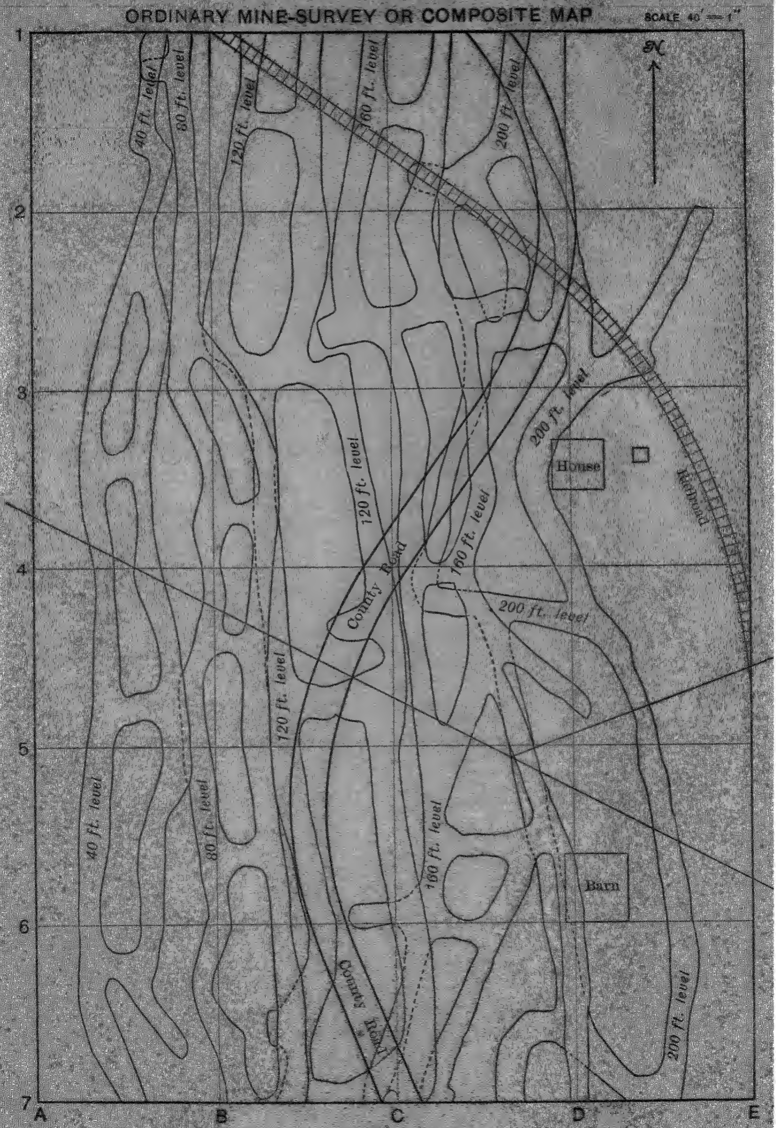

ORDINARY MINE-SURVEY OR COMPOSITE MAP
SCALE 40' = 1"
N
40 ft. level
80 ft. level
120 ft. level
160 ft. level
200 ft. level
County Road
House
Barn
Railroad
1
2
3
4
5
6
7
A
B
C
D
E

FIG. 1.

ORDINARY MINE-SURVEY OR COMPOSITE MAP

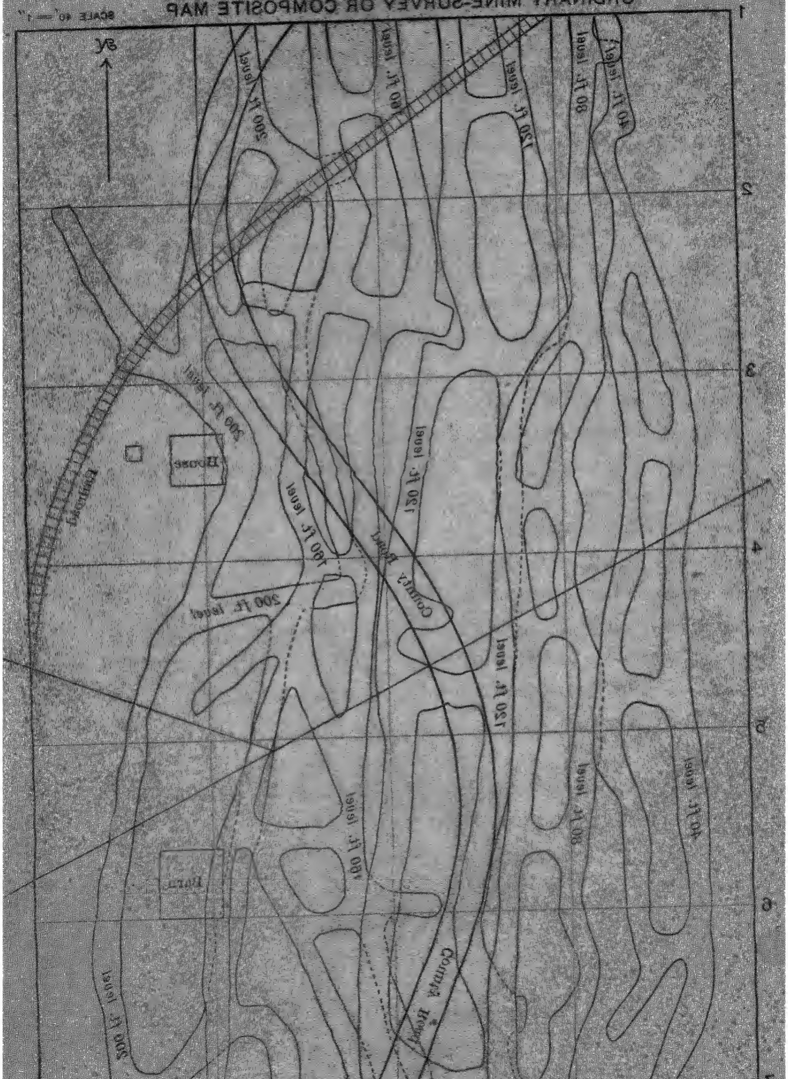


FIG. 1.

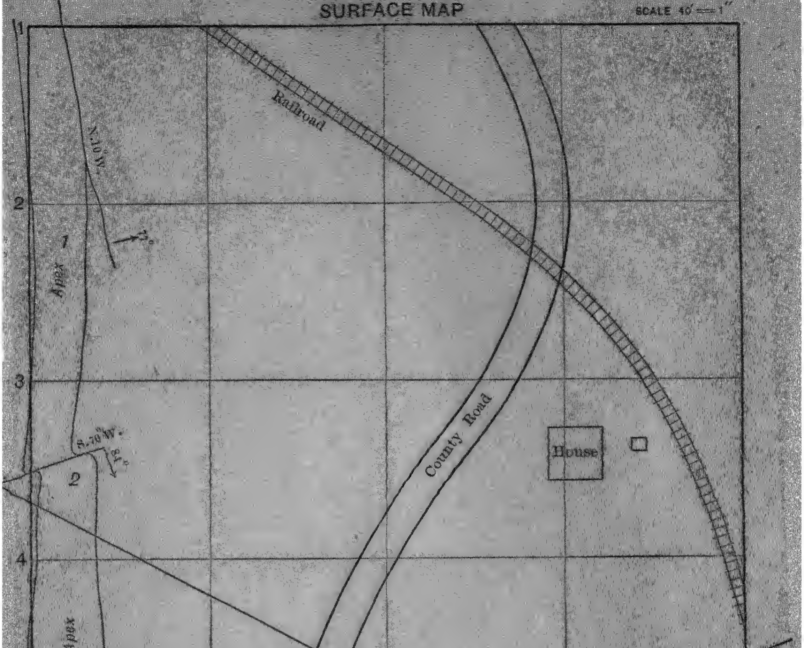

SURFACE MAP
SCALE 40' = 1"
1
2
3
4
5
6
7
A
B
C
D
E
Railroad
County Road
County Road
House
Barn
N.10°W.
S.70°W.
Apex
Apex
1
2
3
4

FIG. 2.

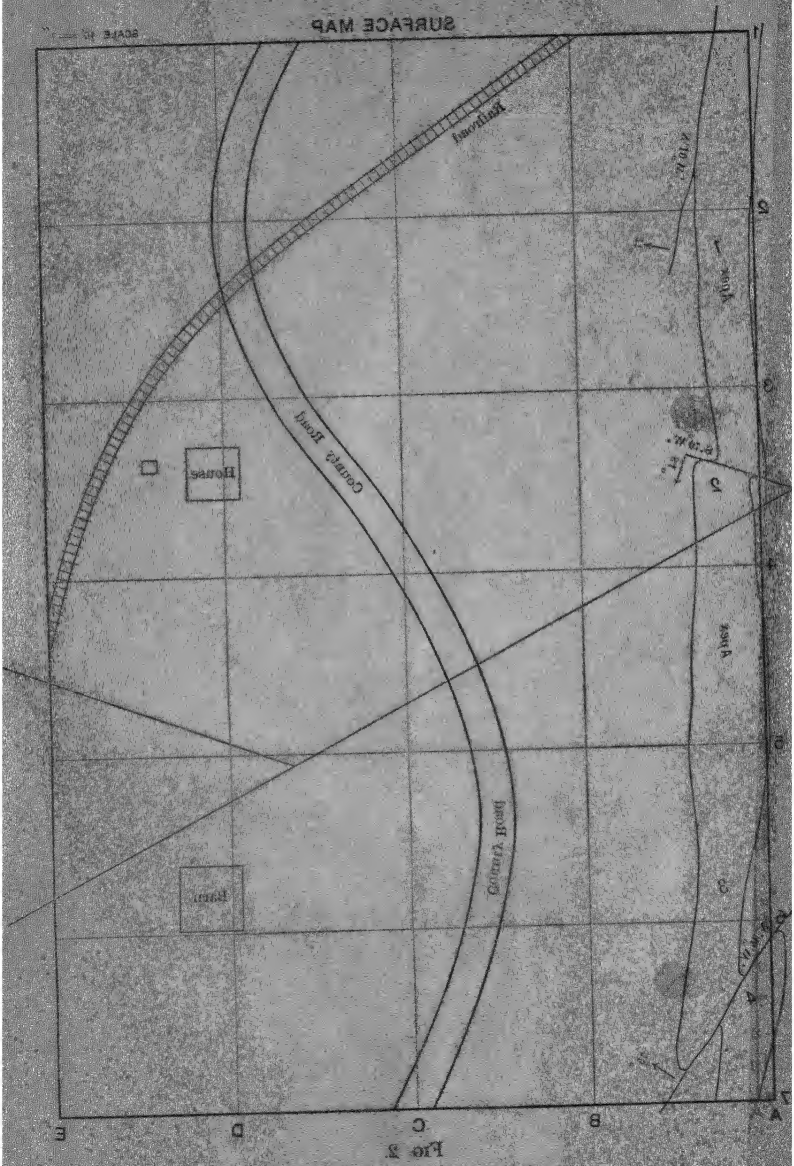

SURFACE MAP
Railroad
County Road
County Road
House
Barn
Apex
Apex
A
B
C
D
E
1
2
3
4
5
6
7

Fig. 2.

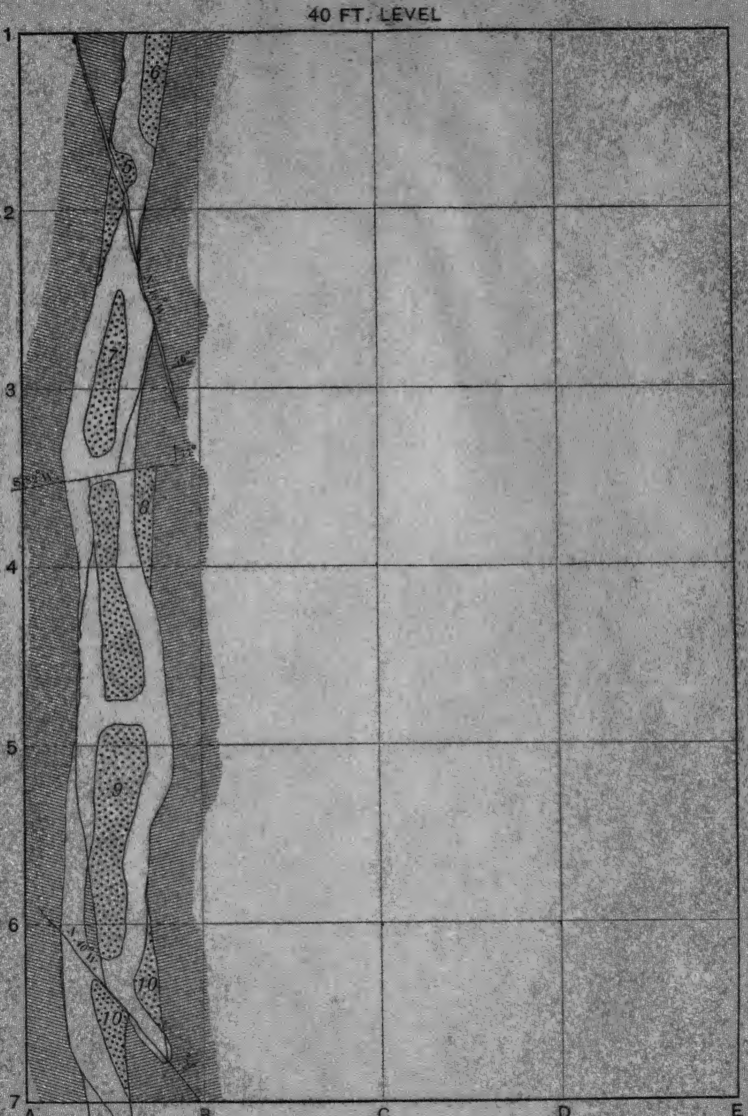

40 FT. LEVEL
1
2
3
4
5
6
7
A
B
C
D
E
6
5
7
8
9
10
10
LEGEND
FOOT-WALL
ORE
HANGING-WALL

Fig. 3.

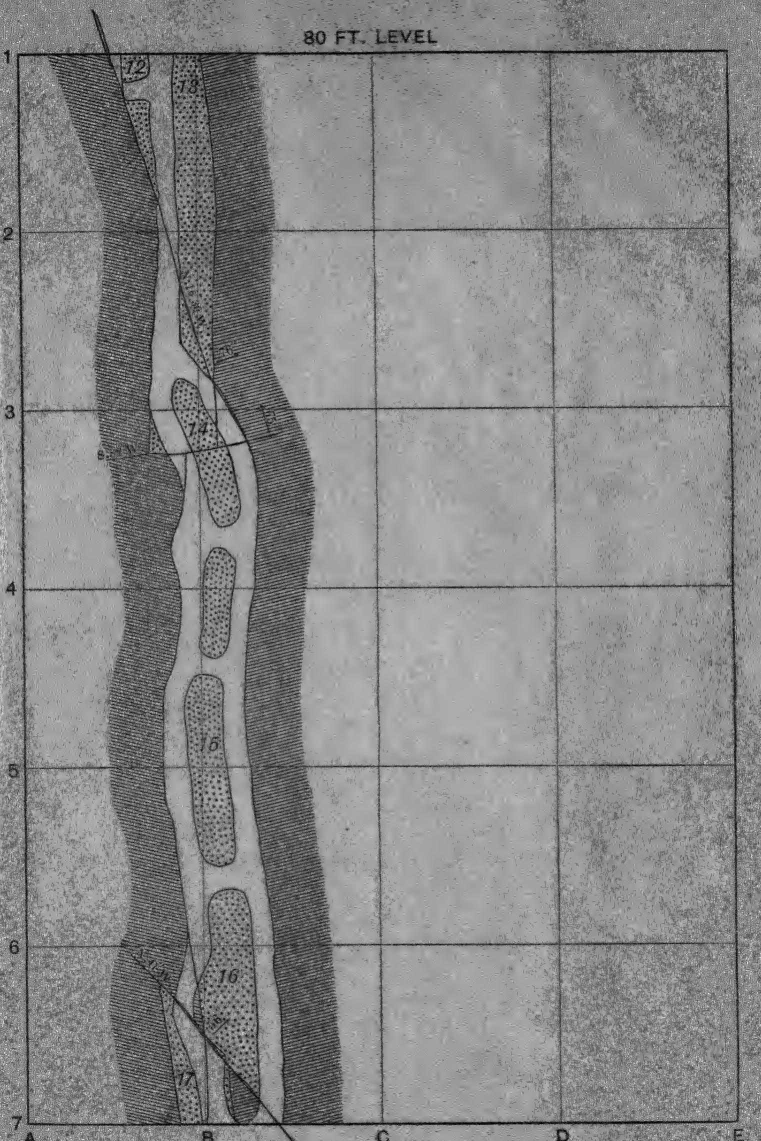


FIG. 4.

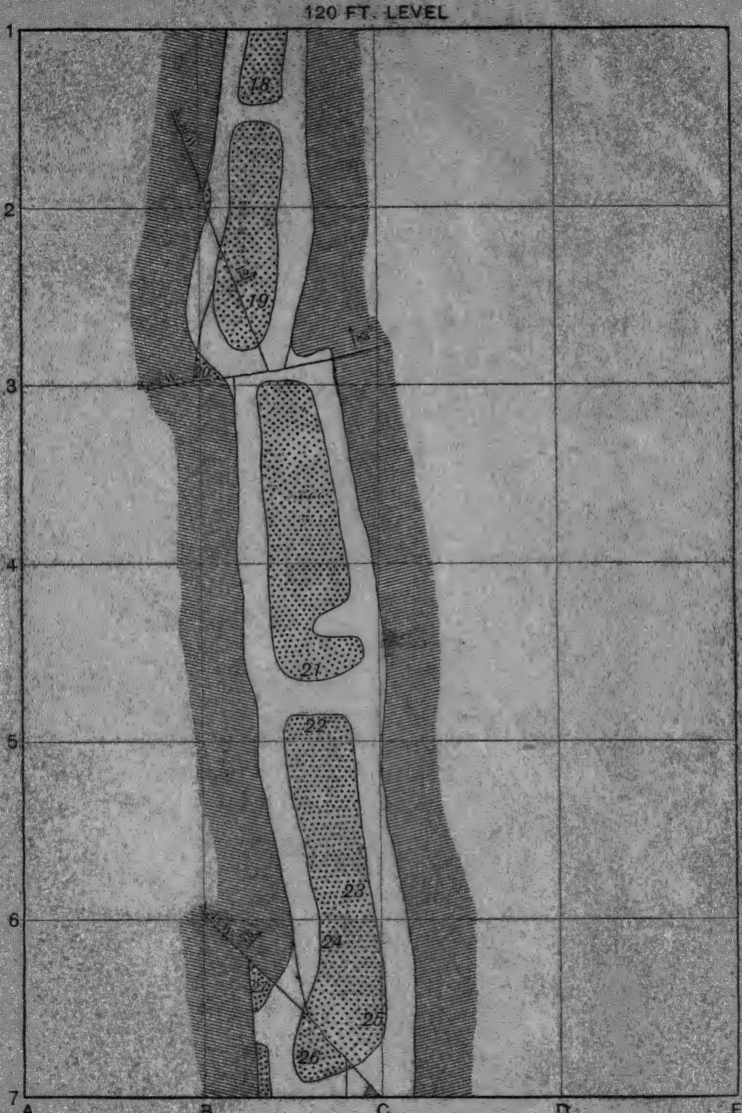
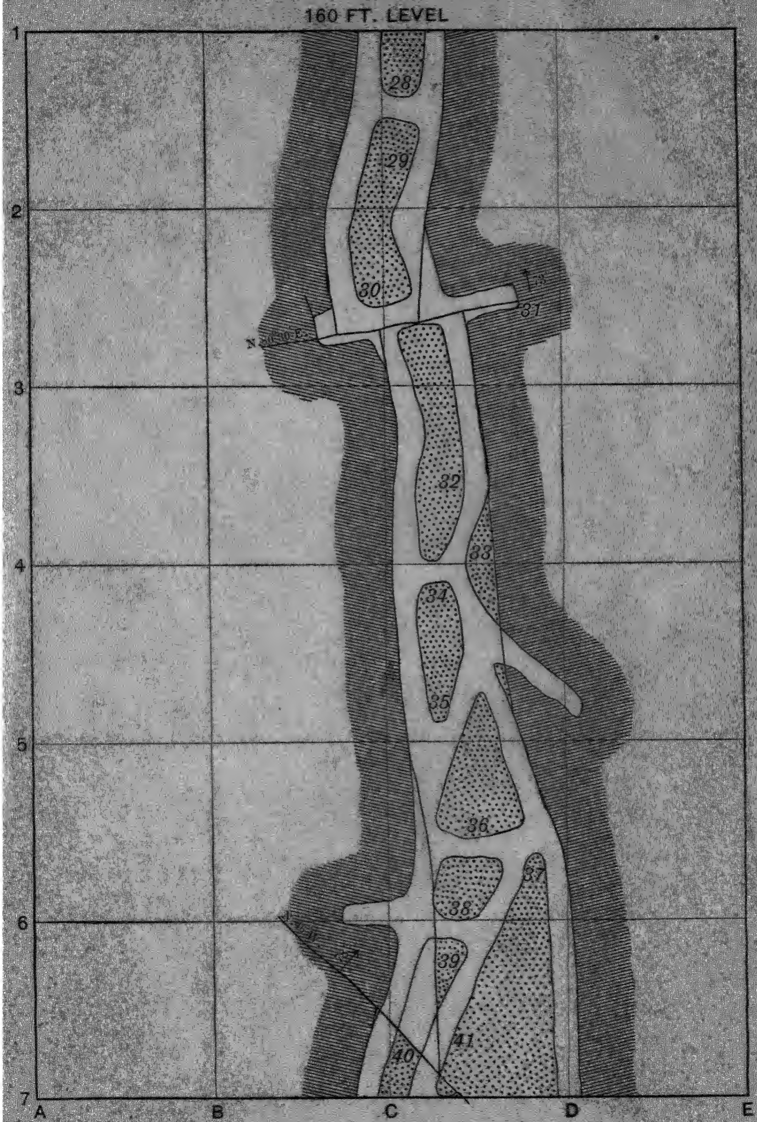


FIG. 5.


160 FT. LEVEL
1
2
3
4
5
6
7
A
B
C
D
E
28
29
30
31
32
33
34
35
36
37
38
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40
41

FIG. 6.

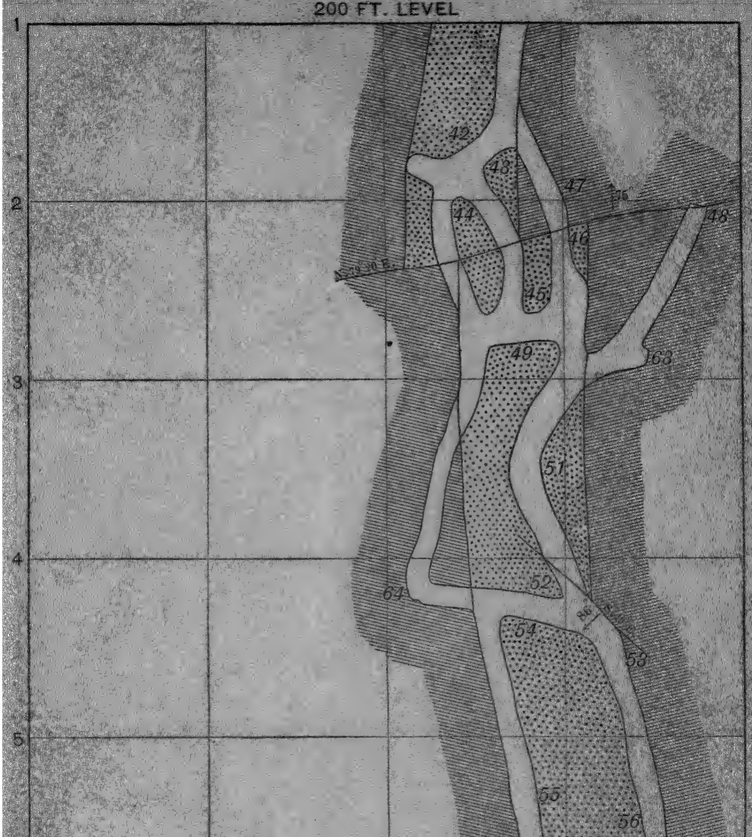
200 FT. LEVEL
1
2
3
4
5
6
7
A
B
C
D
E
42
43
44
45
46
47
48
49
51
52
53
54
55
56
57
58
59
60
61
62
63
64
N.47°30'W.

FIG. 7.

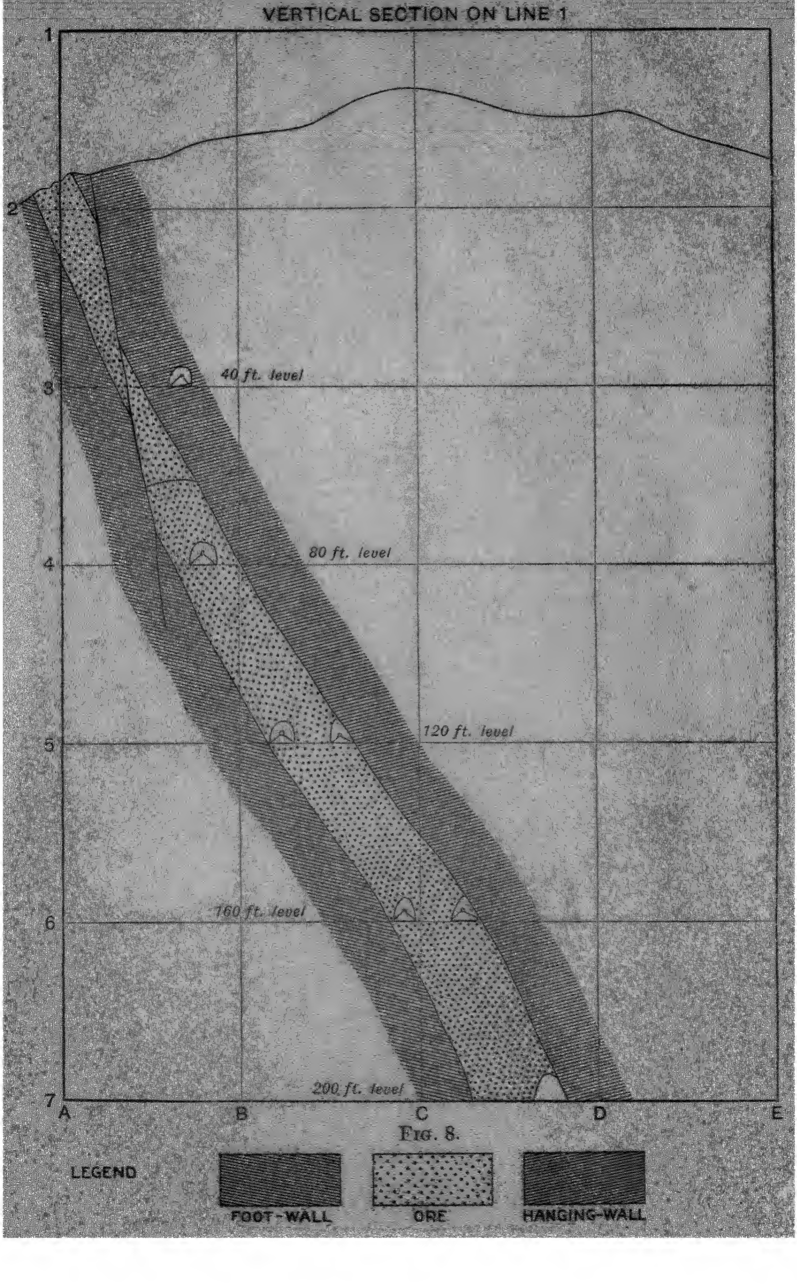
VERTICAL SECTION ON LINE 1
1
2
3
4
5
6
7
40 ft. level
80 ft. level
120 ft. level
160 ft. level
200 ft. level
A
B
C
D
E

FIG. 8.

LEGEND
FOOT-WALL
ORE
HANGING-WALL

VERTICAL SECTION ON LINE 2

FIG. 9.

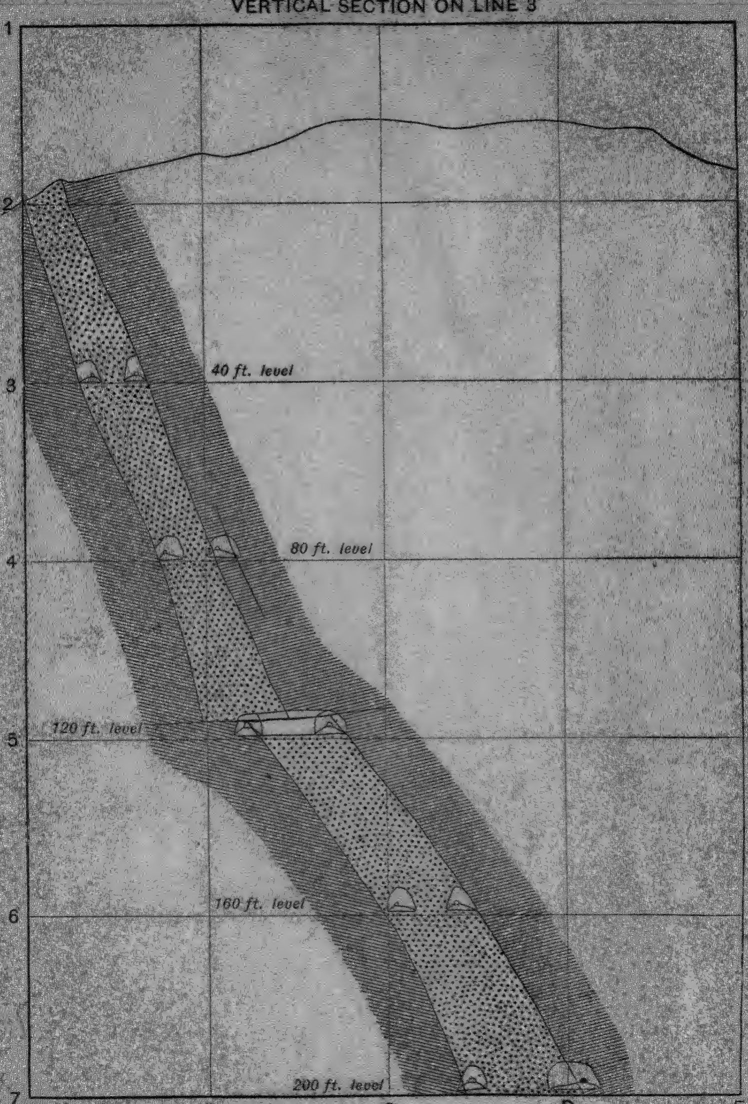
VERTICAL SECTION ON LINE 3
1
2
3
4
5
6
7
40 ft. level
80 ft. level
120 ft. level
160 ft. level
200 ft. level
A
B
C
D
E

FIG. 10.

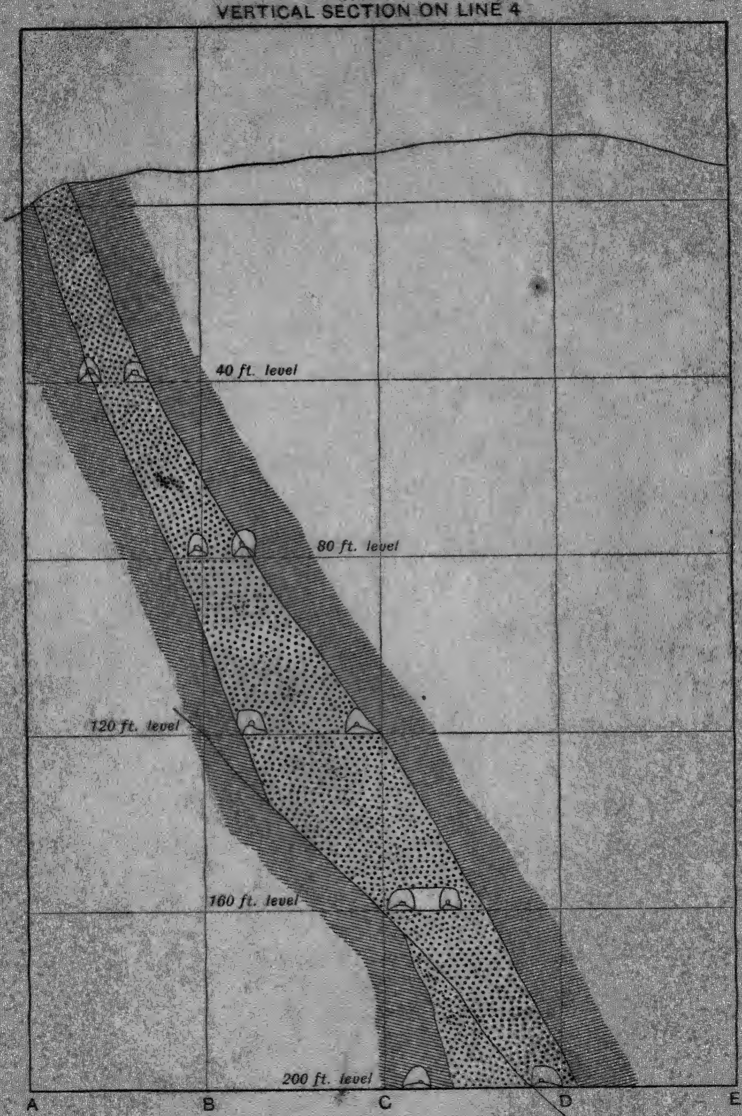
VERTICAL SECTION ON LINE 4
40 ft. level
80 ft. level
120 ft. level
160 ft. level
200 ft. level
A
B
C
D
E

FIG. 11.

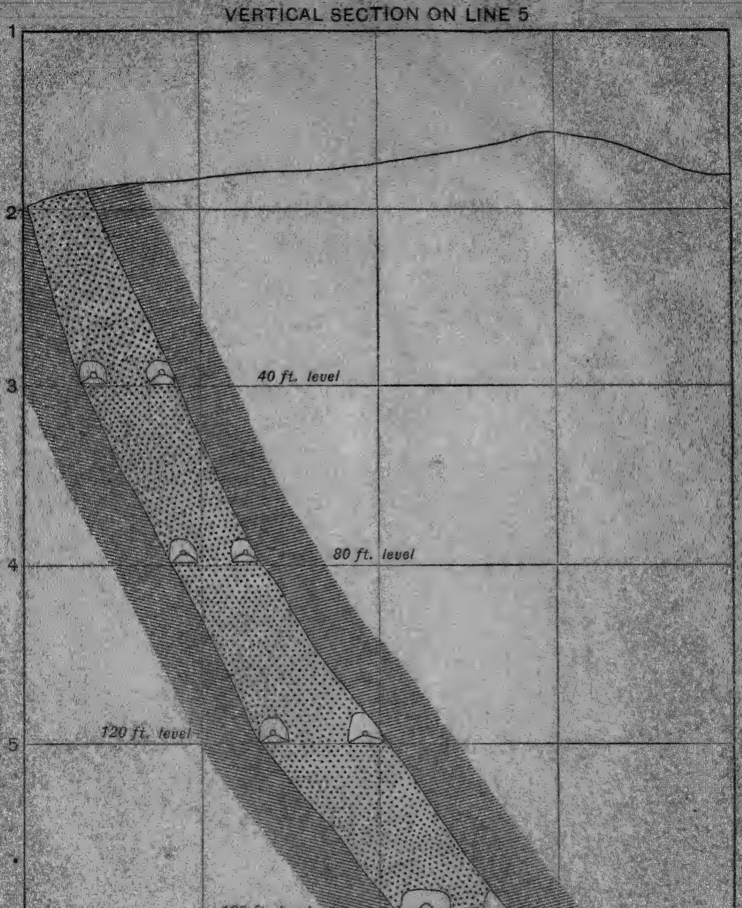
VERTICAL SECTION ON LINE 5
1
2
3
4
5
6
7
40 ft. level
80 ft. level
120 ft. level
160 ft. level
200 ft. level
A
B
C
D
E

FIG. 12.

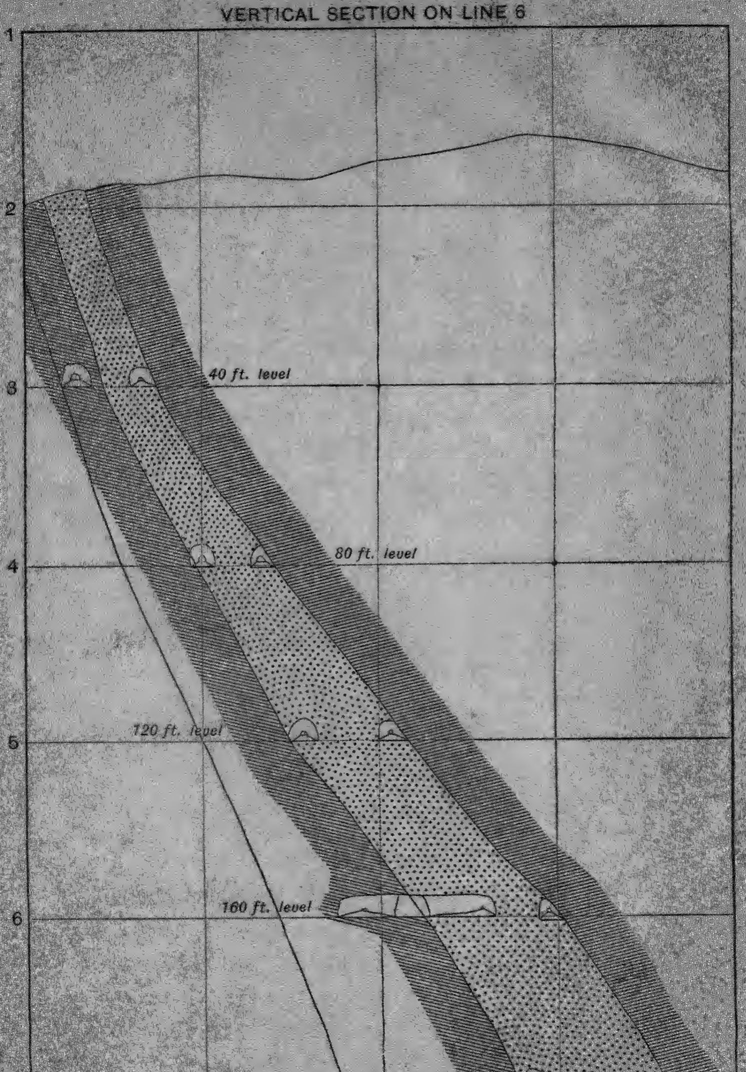
VERTICAL SECTION ON LINE 6
1
2
3
4
5
6
7
40 ft. level
80 ft. level
120 ft. level
160 ft. level
200 ft. level
A
B
C
D
E

FIG. 13.

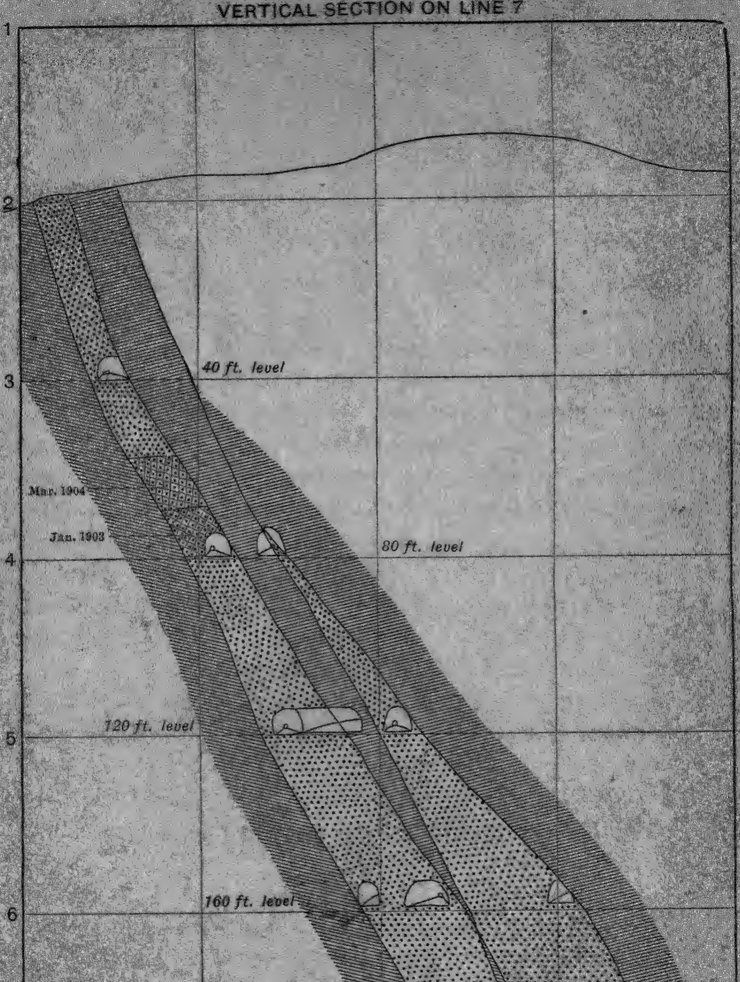
VERTICAL SECTION ON LINE 7
1
2
3
4
5
6
7
A
B
C
D
E
40 ft. level
80 ft. level
120 ft. level
160 ft. level
200 ft. level
Mar. 1904
Jan. 1903
Feb. 1903
March 1903

FIG. 14.

separate official, a competent mining-geologist, whose duty it should be to follow continuously all workings and surveys, and note with precision those indications which hard-worked superintendents, foremen and surveyors, however intelligent, might easily overlook or fail to record. The proper man for this most important work is a man who has nothing else to do, and who will do this one thing with industry, enthusiasm and technical knowledge.

Description and Discussion of Illustrative Drawings.

These drawings represent an imaginary mine, presenting the ordinary conditions of practice.

Fig. 1 shows an ordinary mine-map, sometimes known as a composite map. This is useful only for showing the relations of the workings to each other and to the boundary-lines of the property. It does not form a record of the ore-bodies encountered, or the disturbances to which they may have been subjected, nor has it any great value as a guide in further developments.

In practice, this map would be tinted with a different color for each level. In the engraving, these colors are omitted, since the different tints, as well as the county-road on the surface, can be easily distinguished without such aid. It is evident upon an inspection of the map, that, since the levels at successively increasing depths (40 ft. vertically apart) are situated correspondingly further to the east, while they have a general north-and-south direction, the ore-deposit strikes N–S., and dips E. But this is all that the map can tell us concerning it.

Figs. 2, 3, 4, 5, 6 and 7 are the individual level-sheet geological maps. Each of these level-sheets is traced directly from the ordinary survey-map, after which the geology, as exposed in the openings and determined by careful examination, is platted on the map, care being taken to note the strike and dip of all faults, spurs and intersecting veins. Tracing-cloth is always used for these maps, both for speed and convenience in tracing from the working survey-map, and for the further reason that, when the level-sheets are in the holder, at least three sets of levels can always be seen through the translucent cloth, thereby affording an opportunity to determine the dip and

trend of the ore-shoots, and consequently to project new workings with much greater ease than if observations were limited to a single sheet.

Fig. 2 (the surface-map) shows the outcrop of the ore-body a little further west than the line of the 40-ft. level in Figs. 1 and 3.

Figs. 8, 9, 10, 11, 12, 13 and 14 are vertical sections showing workings and geology. These sections, taken directly from the horizontal level-sheets, afford a very convenient means of studying the vein-structure, and at the same time of keeping a record of the ground stoped during each calendar month.

In addition to these advantages, the vertical sections afford an almost perfect check on the geology, which is nearly always noted first on the horizontal levels. Any errors, either in observation or interpretation, that may have crept into the geologist's work, are sure to be detected when the vertical sections are platted.

Genesis of the Ore-Deposits at Bingham, Utah.*

BY J. M. BOUTWELL, WASHINGTON, D. C.

(Washington Meeting, May, 1905.)

I. *Introduction.*

THE object of this paper is to present a concise statement on the genesis of the copper- and lead-deposits of the Bingham

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Mining District, Utah. It is, essentially, a condensation of a chapter in a detailed report on this district, together with so much on geologic features and on the character and occurrence of the ores as bears on the problems of ore-deposition.[1] The studies upon which the paper is based were undertaken in 1900 under the direction of S. F. Emmons, Geologist-in-Charge of the Section of Metalliferous Deposits, U. S. Geological Survey; and a little additional data was secured in subsequent years. The evidence then obtained as to the genesis of the replacement copper-ores has led to conclusions which differ somewhat from explanations hitherto current. Accordingly, it seems desirable briefly to present the facts, together with the resulting conclusions, in a separate paper.

II. *General Geography.*

The Bingham district is the leading copper-producing camp in Utah. It is situated in the north central part of the State (Lat. 112° 9′ N., Long. 40° 32′ W.) in the Oquirrh mountains, 20 miles southwest of Salt Lake City. The main slopes of the Oquirrhs, rising steeply from elevations of about 5,000 ft. on the surrounding desert to elevations of 10,000 ft. on the main divide, are deeply dissected by many narrow, steep-walled canyons. Toward the northern end of the range a prominent canyon follows a crescentic course northeastward across its eastern slope, and receives several tributary canyons from the west. This is Bingham canyon, which has given the name to the mining-district, and its drainage-basin embraces the principal mining-localities which constitute the Bingham district.

This district extends from the Jordan valley on the east across the eastern slope of the range and the main divide, and well down the western slope. The productive region proper, occupied by about 125 properties, embraces an area of about 15 sq. miles; and the five great properties, which produce the bulk of the present output, lie within a single square mile. Bingham canyon with its tributaries drains the central and more important portions. The slopes present a very rugged,

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[1] The complete report, *Professional Paper No.* 38, *U. S. Geological Survey* (1905), with maps, sections and illustrations, may be obtained free upon request to the Director U. S. Geological Survey, Washington, D. C.

scantily-végetated surface that rises precipitously from narrow partly-graded bottoms to steep ledgy divides.

Bingham precinct, including the principal settlement scattered along the bottom of Lower Bingham canyon and several smaller settlements which have grown up about the larger mines, has a population of about 2,000 (1,872, Census of 1900). Railroad connection with the trunk-line of the Rio Grande Western Railroad at Bingham Junction (11 miles south of Salt Lake City) is by a branch line 14 miles in length.

The region as a whole is poorly watered. In this immediate

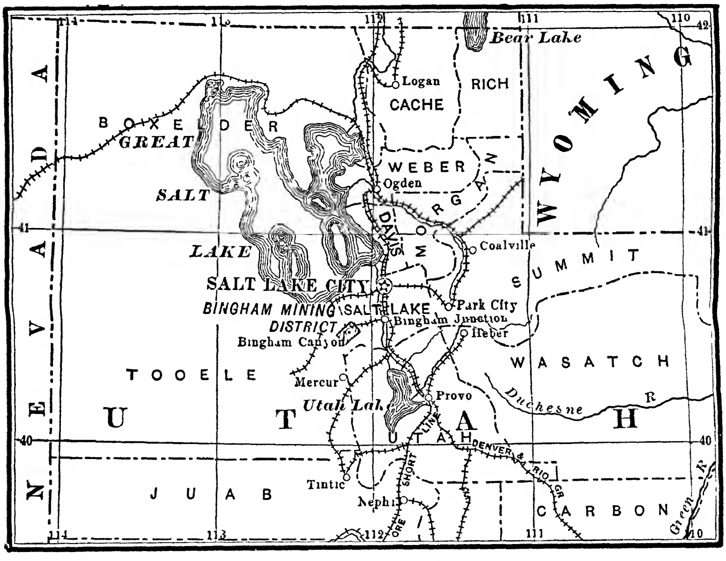

FIG. 1.—MAP SHOWING SITUATION OF THE BINGHAM MINING DISTRICT.

section, only the main canyons and their larger tributaries carry water. A few good springs are known, though in the vicinity of the mining-regions the main sources of water-supply are subterranean courses tapped by underground workings.

Vegetation is relatively sparse. Sagebrush (*artemisia*) is the prevailing growth on the lower slopes adjoining the deserts. Scrub oak with an occasional cactus plant (*puntia vulgaris*), juniper, spruces and some pine characterize the middle elevations; and mountain mahogany, certain grasses, and Alpine varieties of wild flowers alone inhabit the higher peaks.

The present topography of the Bingham region is composite.

It indicates that it has been produced during several distinct periods. The prevailing areas are fairly-graded middle slopes or uplands. Above them rise ledgy ungraded peaks along the main divides; and below, these middle slopes fall off abruptly by precipitous cliffs to narrow partly-graded canyons. The present bottoms of these canyons frequently lie upon gravel deposits from 50 to 200 ft. thick. As a whole, this region presents a rugged mountainous topography of strong relief.

This district has experienced an unusually varied mining history. It first yielded copper carbonate ores—the first shipment of ores from Utah being copper-ore from this district—then it attracted attention by its production of placer-gold, amounting in value to about $1,500,000; subsequently it yielded, successively, carbonate and sulphide lead-ores, oxidized gold-ores, sulphide argentiferous lead-ores, and finally, during the last decade, has gained its present and greatest reputation by its large and increasing production of sulphide copper-ore. The annual output, as reported for 1904, is nearly 1,000,000 tons of ore. The total output is valued at about $40,000,000.

III. *General Geology.*

1. *Sedimentary Rocks.*—The sedimentary section exposed in this district embraces several thousand feet of massive quartzite, thin intercalated limestones, and calcareous shales. The calcareous members have exerted a controlling influence on ore-deposition. This great quartzite section may be broadly divided on lithologic grounds into two parts: a lower which is distinguished by a few comparatively-thin interbedded limestones; and an upper which is distinguished by intercalated black calcareous shales, sandstones and impure limestones.

The age of this succession of sediments, as proved by faunas from the limestones, sandstones and shales, is upper Carboniferous (Pennsylvanian).

The sedimentary rocks in this and adjacent districts may be tentatively correlated on paleontologic, lithologic or stratigraphic evidence with part of the general section determined by the geologists of the Fortieth Parallel Survey as the Weber quartzite and Wasatch limestone.

The Bingham series is probably equivalent to a portion of the Weber quartzite.

At Park City, in the Wasatch range, the main quartzite (known locally as the Ontario quartzite) overlies limestones of Wasatch age, and is probably equivalent to the upper portion of the Weber quartzite. At Mercur, a few miles SSW. of Bingham in the Oquirrh range, the principal ore-bearing horizon is a great blue limestone, in the lower intercalated series, which is considered equivalent to the Wasatch limestone, while the upper intercalated series may be equivalent to the Weber quartzite.[2] At Tintic the chief ore-bearing members are the Eureka and Godiva limestones, which carry lower Carboniferous faunas. At Alta, at the head of Little Cottonwood canyon, the section was examined by the geologists of the Fortieth Parallel Survey, and the limestone, in which most of the important mines of the district are located, was considered as the lower part of the Wasatch limestone.[3] In brief, it appears: (1) that the Wasatch limestone (lower Carboniferous of the Fortieth Parallel Survey) forms the country-rock for the principal ore-bodies at Tintic, Alta and Mercur; (2) that the equivalent of the Weber formation (upper Carboniferous of the Fortieth Parallel Survey) contains the more valuable ore-bodies at Bingham and Park City; (3) that some ore-bearing beds at Park City are of still later age, and thus (4) that the ore-bearing beds of Bingham are equivalent to some of those at Park City, slightly younger than those at Tintic, Alta and Mercur, and older than the youngest at Park City.

2. *Igneous Rocks.*—Igneous rocks of two types occur in this district. One type, which is widely distributed in the forms of dikes, sills, irregular laccoliths and stocks, is intrusive in origin. The other type, which is restricted to the lower portion of the outer (eastern) part of the range and appears to blanket an old land-surface, is extrusive in origin. The various facies of both types exhibit striking lithologic similarity. This fact, together with the absence of distinct cases of rock of one type cutting that of another, makes the determination of their relations somewhat uncertain. It appears, however, that the intrusives and their inclosing sediments were deeply dissected before ex-

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[2] Spurr, J. E. Personal communication to the writer, March 24, 1903.

[3] Emmons, S. F. *Geographical Exploration of the Fortieth Parallel*, vol. ii., p. 364.

trusion occurred; in short, that extrusion followed intrusion at a considerably later period.

The intrusive rocks include two structural types, a fine, dark-gray, even-grained, granular type, and a coarse, porphyritic type. The rocks of the granular type have, in hand-specimens, the general aspect of diorite, but on microscopic and chemical study they prove to be monzonite. Those of the porphyritic type show, in thin section, a little free quartz, and appear to carry a sufficiently lower proportion of potash feldspars to render them diorite-porphyries, but chemical analysis reveals the presence of sufficient potash in the ground-mass to raise them proportionately high enough for monzonite-porphyry. Under the microscope the extrusive rock appears to be hornblende-biotite-andesite. Chemical analysis, however, shows a high percentage of potash, which tends to indicate that this rock belongs to the extrusive type corresponding to monzonite, namely, latite. In brief, these closely related species appear on microscopical and chemical determination to be as follows: the granular intrusive, monzonite; the porphyritic intrusive, monzonite-porphyry; and the extrusive, latite.

The extrusives, so far as known, neither carry mineral values themselves nor induce ore-deposition in adjacent country-rock. The intrusives both contain values and induce ore-deposition in the inclosing country-rock.

3. *Areal Geology.*—The general distribution of the sedimentary and igneous rocks is simple, but the detailed distribution is most complex and irregular. Briefly, three limestone series and massive quartzites which separate them, occupy the southern and southeastern portions of the area, and strike, from the main divide on the west, northeastward through the district. A great siliceous upper series of quartzites, calcareous shales and sandstones, and thin limestones overlie them, and occupy the north and northwest half of the area. The intrusives lie, mainly in the southern portion of the area in two great divisions, the lower lying south of the middle limestone series (Old Jordan and Commercial limestones) and the upper lying north of and above this series. The sediments and their associated intrusives disappear on the east along a generally N–S. line beneath the later volcanics, which, in turn, are blanketed by extensive Quaternary deposits.

In the absence of the geological map of this area it may be roughly pictured as follows: conceive an oblong area in which the four points of the compass lie at the four corners; draw a straight line from the north corner to the middle of the southeast side, and a second line from the same corner to the middle of the southwest side; then the first line will mark the contact between the late deposits (Quaternary and volcanic) on the east, and the Carboniferous on the west; and the second will delimit the great siliceous series on the north from the main mineralized area comprising the limestone series with separating quartzites and intrusives on the south.

4. *Structural Geology.*—The area occupied by this district lies in a broad, shallow, synclinal basin, which pitches gently northward. This basin is limited on the west by an anticline and on the east by a steep upturn. Minor folds occur, but they are relatively unimportant.

Fissures, as passages for ore-bearing agents and as fault-planes on which ore-bodies have been displaced, are the most important features of deformation. Complex and recurrent fissuring, fracturing and crushing, of an intense nature, took place at several periods throughout the district.

The fractures of Bingham vary widely in general character. They range from a net-work of irregular cracks and zones of intense crushing to simple individual fissures and zones of fissures.

The fissures continue for many hundred feet along their strike and have not as yet given out in depth. They cut every formation and every kind of rock in the district, and pass continuously from one formation into another.

The fissures and fractures trend and dip toward all points of the compass. Intersections and comparisons of physical features indicate that the fissuring occurred in at least three distinct periods, as follows: in NE–SW. (and N–S.); then in NW–SE., and finally in NE–SW. directions.

The geologic age of the fissuring is not closely limited by the evidence at hand. It appears that the earliest fissuring recognized did not take place before Upper Carboniferous time, that some probably occurred in late Tertiary time, and that movements are probably still in progress.

In connection with this extensive and complex fissuring in

localities where the contacts of massive limestone with quartzites, or of shale-members, afford the necessary distinctive datum-planes, important faults and zones of faulting have been found, cutting the country-rock and truncating ore-bodies. Faults with trends, dips and displacements of nearly every conceivable character were studied, but no constant direction of movement was observed. Displacement may be expected in any direction. There is no constant relation between the direction of displacement and the dip or strike of a fault-plane. The amount of displacement proved underground rarely exceeds 150 ft., and, except on innumerable minor faults, averages between 50 and 100 feet.

IV. *General Character of the Ore-Deposits.*

The Bingham deposits yield ores of copper, lead, silver and gold. The present output is made up almost entirely of copper sulphide ore, and of comparatively small amounts of argentiferous lead-ore.

The copper-ores are chiefly low-grade sulphides, massive chalcopyrite and pyrite. The grade of these ores is raised, however, by comparatively small amounts of the black copper sulphides, chalcocite and tetrahedrite, and of the oxide, tenorite. Quartz is the principal gangue-mineral. The gold-copper milling-ore from monzonite is chiefly composed of chalcopyrite and pyrite with a little bornite and magnetite and a highly siliceous gangue. The argentiferous lead-ores are principally made up of galena, tetrahedrite and zinc blende.

The low-grade sulphide copper-ore occurs as a massive bedded deposit in marbleized limestone. The auriferous copper-ore is found disseminated throughout large masses of monzonite, more particularly, however, in fractured, crushed and altered areas. The argentiferous lead-ores, carrying accessory gold and copper with associated zinc, are almost entirely restricted to veins and lodes.

Differences in their composition, structure and geologic occurrence, indicative of genetic differences, throw these ores into three distinct classes. The genesis of the Bingham ores may thus be considered under the following heads: Genesis of the Disseminated Ore in Monzonite; Genesis of the Ore in Fissures; Genesis of the Copper-Ore in Limestone.

V. *Genesis of Disseminated Ore in Monzonite.*

1. *General.*—Copper-ore occurs in the igneous rocks of this district in two forms, (1) impregnations of only the immediate walls of normal ore-bearing fissures, and (2) disseminations through extensive masses of altered monzonite. The former is characterized by narrow zones of cupriferous granular and semi-crystalline pyrite which is present most abundantly at fissures, gradually decreases in amount away from them, and fades out within a short distance. This alteration and pyritization of the monzonite immediately adjacent to normal fissures is so clearly incident to the formation of the lodes that its consideration will naturally be taken up in connection with the explanation of the origin of the ore in fissures. The disseminated copper-ore, however, has not been observed to be associated with normal ore-bearing fissures, but appears in certain significant characteristics to form a separate type. The pyrite in the altered monzonite adjacent to ore-bearing fissures is clearly secondary. The immediate problem remaining is then whether the grains of pyrite and chalcopyrite, now thoroughly disseminated through extensive masses of monzonite, entered upon their present state at the time of the igneous invasions, or subsequently through secondary agencies.

2. *Character and Occurrence.*—The occurrence of disseminated ore in igneous rock in Bingham, which is most thoroughly known, and which thus affords the most favorable opportunity for study, is, in the intrusive body at upper Bingham, known as the Bingham laccolith. This irregular mass has been extensively explored by tunnels, test-pits, borings, and shafts, and thoroughly sampled throughout. In a general way this exploration shows that this extensive mass of monzonite carries, disseminated throughout its areal extent, so far as known, irregular grains of pyrite and chalcopyrite; that the known mineralized tract is characterized, not by a series or succession of normal fissures, but by innumerable thin, unsystematized parting-planes; that the rock is exceedingly altered by bleaching and silicification, especially in and adjacent to zonal areas of strong shattering; that assays show copper to be lowest at the surface and in old workings; that, in relatively firm, unaltered rock, the copper-ore lies in flat scales and films on the silicified

walls of cracks, while in areas of great shattering and alteration it occurs abundantly, both on quartz-coated cracks and disseminated in the silicified bleached walls. In brief, copper is disseminated at a depth throughout the monzonite, and occurs most abundantly in areas of maximum crushing, silicification and alteration.

3. *Genesis.*—The general character and occurrence apparently indicate a relation between quality of ore and degree of opening, alteration and silicification, and suggest that the metallic contents reached their present state through secondary agencies.

Detailed evidence afforded by fresh and altered monzonite, both in hand-specimens and in thin sections, tends to confirm this conclusion based on general criteria. In fresh, slightly-parted specimens of monzonite, pyrite and chalcopyrite, if present, occur sparingly within the mass, and seem to be almost entirely restricted to parting-planes. Examination of thin sections shows that the chief constituents named, in the order of their predominance, are,—orthoclase, plagioclase, augite, biotite, and a little hornblende and quartz. The biotite, and less abundantly the augite, include numerous grains of a dark-gray metal, which is probably magnetite. (Fig. 2.) In slightly altered monzonite the augite shows incipient alteration on its margins to uralitic hornblende, the biotite appears paler, and the feldspar shows passage into sericite. A specimen of highly altered monzonite has lost the dark color and compact body and shows, instead, a dull, light-gray color, a slightly porous structure, and abundant quartz in veinlets and in blotches upon the walls of parting-planes. Under the microscope it is seen that the proportion of acid or salic contents, to the ferromagnesian or femic, has greatly increased. Conspicuous areas of granular quartz are numerous, the orthoclase is highly sericitized, and the femic minerals are represented by numerous irregular patches of small individuals or flakes of dense brown biotite. The quartz and sericite are clearly secondary, and though no direct proof of the age of the biotite has been found, it resembles secondary biotite and may be secondary also. Magnetite, excepting occasional grains, has disappeared, and large amounts of chalcopyrite and pyrite are present in the form of rounded grains, chains and veinlets embedded in

secondary quartz, flaky biotite, and sericitized feldspar (Figs. 3 and 4). From the above-stated field-observations, and from accordant detailed evidence, it would appear that the absence of chalcopyrite and pyrite in unparted, unaltered monzonite, their abundant occurrence on secondary parting-planes, and their intimate association with sericitized feldspar, a biotite of possible secondary origin, and secondary quartz, show that they attained their present state considerably later than the intrusion, and are thus of secondary origin.

Although perfect proof can hardly be expected, it seems improbable that they were developed and deposited in their present state, without the introduction of additional elements from without the intrusive mass. The observed stages of metasomatic alteration of magnetite, culminating in the occurrence of minute, ill-defined cores of magnetite without secondary sulphides, and finally in the total disappearance of magnetite, indicate one source of the iron of the chalcopyrite and pyrite. Additional iron was doubtless derived from original augite and biotite. Any additional sulphur, which may have been required, was probably supplied from without, perhaps from sulphurous gases. The immediate source of the copper and gold remains unproved. If any of the pyrite is original, some of each of these other values might have been included as impurities, but the large remainder can hardly be explained, except by subsequent introduction from without.

The demand for sulphur, copper and gold by such subsequent introduction raises a question as to the nature of their carrier. Evidence on this point is found in their occurrence and the probable manner of alteration.

The areas in which this later deposition of metallic sulphides appears to have attained its maximum are characterized by innumerable fractures, joints and other parting-planes of various kinds. They are regions, then, in which the country has been broken and penetrated by minute passage-ways. Further, the ore occurs, not as distinct seams or veinlets filling narrow crevices, but as grains disseminated throughout the altered intrusive. Accordingly, it is not improbable that the transporting and altering agent possessed the properties of an aqueous solution.

The probable temperature of these solutions may be deter-

mined by criteria which Lindgren has described. Thus, he finds that a narrow rim of calcite or quartz, inclosing crystals of pyrite, indicates their deposition from hot waters (hydrothermal metasomatism).[4] He gives, as additional characteristics of such processes (hydrothermal metasomatism), the development of sericite, "probably the most universal of all minerals forming in altered rocks near fissures,"[5] and the frequently observed relation between the development of sericite and of quartz. Regarding this relation he has observed that

"sericite forms easily and abundantly from orthoclase and microcline (*with equal ease from oligoclase, andesine and labradorite*—J. M B.), the foils and fibers developing on cleavage-planes and cracks until they invade the whole crystal. The reaction may be chemically expressed as follows, water containing carbon dioxide being the only reagent necessary:

$$3KAlSi_3O_8 + H_2O + CO_2 = KH_2Al_3(SiO_4)_3 + K_2CO_3 + 6SiO_2.$$

"This reaction is accompanied by a considerable reduction of volume, the sericite occupying less than one-half of the original volume of the orthoclase. If SiO_2 separates as quartz, the aggregate volume of the two secondary minerals shows a reduction of 13 per cent. from the volume of the orthoclase. Very often, however, the quartz is carried away in solution, to be deposited in neighboring open spaces."[6]

In the altered, mineralized monzonite at Bingham these criteria were observed. Thus the presence of quartz rims about the grains of pyrite and chalcopyrite is common. Sericitization of feldspars is pronounced (Figs. 3 and 4) and silicification of the country-rock, and reduction in its volume are perhaps the most widespread and noticeable features of the alteration. In the light of this evidence, and in view of the requirement that some of the gold, copper and silver should have been derived from without, it seems highly probable that the hydrous solutions were hot. In brief, evidence tends to show that heated hydrous solutions altered the rock-making, and metallic minerals, constituting the igneous rock, probably introduced copper, gold and sulphur, and, at that time, subse-

[4] Lindgren, Waldemar: Gold-Quartz Veins in Nevada City and Grass Valley; 17*th Annual Report of the U. S. Geological Survey*, pt. 2, p. 95.

[5] Lindgren, Waldemar: Metasomatic Processes in Fissure-Veins; *Genesis of Ore-Deposits* (1902), A. I. M. E., p. 527.

[6] Lindgren, Waldemar: Metasomatic Processes in Fissure-Veins; *Genesis of Ore-Deposits* (1902), A. I. M. E., p. 528.

quent to the date of intrusion, generated the later metallic minerals, pyrite and chalcopyrite.

4. *Superficial Alteration.*—Recent superficial alteration has followed the deposition of chalcopyrite and pyrite. Pyrite about its periphery and along cracks which traverse these planes may be seen going over to limonite. This fact, as observed in hand-specimens of gold-ores, doubtless explains the relative enrichment of gold values proved by assays to exist in the outer or surface portions of test-tunnels in these copper- and gold-bearing intrusives. The brilliant tarnish of grains of chalcopyrite indicates a beginning of alteration, and thin rims of a dark grayish-black mineral about chalcopyrite, observed under the microscope, suggest continuance of that process and replacement by black copper-sulphide. Although the illustration fails to bring them out, rims of a blue-black metallic sulphide occur around grains of chalcopyrite in the thin section shown in one of the photo-micrographs. The reason for the decrease in assay-values of copper along certain open and water-bearing fracture-zones is doubtless to be found in the well-known fact, that, under the action of surface waters, copper suffers rapid alteration and transportation.

5. *Conclusion.*—It appears then that in the disseminated ores in igneous rock the copper-metals were deposited by hydrothermal action subsequent to the date of igneous intrusion, and that these sulphides are now undergoing normal superficial alteration.

VI. *Genesis of the Ores in Fissures.*

1. *Character.*—The ore occurring in fissures in this district is essentially argentiferous lead-ore carrying minor amounts of copper and gold. It is composed in largest part of the sulphide (galena), and also contains small amounts of lead sulphate (anglesite), lead carbonate (cerussite) and lead oxide (massicot). Massive tetrahedrite of the silver-bearing variety (freibergite) is usually an important accessory, and bears considerable amounts of silver and copper. Zinc blende of massive form is the most abundant gangue-mineral, and quartz, calcite, barite and rhodochrosite are occasionally present in small amount. The silver occurs very largely in galena and tetrahedrite. Pyrargyrite and cerargyrite have been reported.

2. *Occurrence.*—Ore occurs here in fissures, as seams between slickensided walls of normal country-rock, as seams frozen to walls, in zones of these single seams between solid country-rock, and in groups of roughly parallel seams traversing zones of crushed and brecciated material. Both the single mineralized fissure, vein, and the group of veins, lode, are common. The type which most frequently bears ore is a simple fissure characterized by a zone of finely-comminuted country-rock, averaging from 1 to 4 ft. wide, and inclosed between slickensided walls. The veins and lodes traverse rocks of every lithologic type and age in the district. The prevailing trend of the observed lodes is NE–SW. and their prevailing dip is toward the NW. Barren fissures and fractures trend and dip without apparent system toward all points of the compass. As regards the sequence of fracturing, and the deposition of lode-ores, it appears that ore-deposition was preceded by fissuring in NE–SW. directions and followed by faulting on NW–SE. planes, and then on NE–SW. planes. In extent, fissures and fractures have been found to continue several hundred feet along their strike and dip. Their mineral contents, though varying and pinching locally, have not been proved to disappear permanently in either direction.

The strong fissures appear to be the most extensive and most highly mineralized. Localization of pay occurs in both dip-fissures or those lying in the normal fissure and fracture-zone and in strike-fissures or those lying between formations or beds. Shoots in the former, however, though doubtless present, have been only roughly determined as such. Lode-ores in strike-fissures occur in definite shoots with decided pitch. The prevailing structure of the lodes is a banding imparted by parallel pay-streaks, within a crushed zone, and these, in turn are made up of several minerals in massive and semi-crystalline form distributed roughly in bands with ill-defined interlacing boundaries. It is not a typical "crusted" or "crustified" structure, though a general sequence of minerals from wall to core is apparent as follows: sphalerite, tetrahedrite, pyrite and galena, galena and calcite, rhodochrosite and quartz cores.

In brief, the lead-, silver- and copper-minerals, which constitute the fissure-ores, are systematically arranged in rough band in pay-streaks in zones of fracturing which persistently tra

verse every type of country-rock in a generally NE–SW. direction throughout the district.

3. *Deposition.*—The general character of the deposition of the lode-ores is indicated, in part, by the form of the ore-bodies, by the structure of the pay-streaks, and by the structure of the ore. Thus the absence of typically defined, crustified structure and sharply defined bands and lines of infacing crystals, tends to show that the ore cannot be regarded as entirely a deposit formed within pre-existing open spaces. The restriction of these lodes to practically a single system of zones of strong fracturing, the continuity of the breaks regardless of their contents, the unity of the pay-streaks, and the roughly-banded structure, signify that the fractures existed before ore-deposition and offered partly-opened spaces, favorable pathways for the mineral-bearing agent, and suitable areas for ore-deposition. The rough banding and regular succession of the minerals composing the deposits point to a corresponding historical succession in their deposition, and the occasional presence of infacing crystals at the core of some pay-streaks tends to show their deposition from solution.

The extreme regularity of the interlacing boundaries, the intergrowth of arms and lobes of pyrite and galena, the presence of galena surrounding and interlacing with semi-crystalline pyrite, the interweaving of sphalerite and galena, and the close structural relation between sphalerite and tetrahedrite,—in short, the presence, within each band, of considerable portions of the other constituents in massive or crystalline form, tends to show that the fissure-ores were not freely deposited from normal aqueous solutions. These features would rather suggest that the deposition took place from a solution either actually of a pasty, semi-viscous character, or rendered so potentially by pressure, in order to allow apparently contemporaneous deposition throughout the open space.

Filling was frequently supplemented by replacement of walls.

4. *Transporting Agent.*—The physical and chemical character of the agent which introduced the fissure-ores is indicated by the character of its deposits and the influence which it exerted upon the wall-rock.

The occurrence of pay-streaks in thin attenuated plates

along very close fissures, the penetration of filamentous crevices by pyrite veinlets and the structure of the pay-streaks, lead to the conclusion that the ores were deposited from a liquid or from some material that possessed the general properties of a liquid. The character and probable derivation of the contents of this liquid, and evidence that it rose from depth, suggest that the temperature of this liquid was high. The chemical character, judging by its effect on limestone, was that of an acid. Chemical and microscopical study of monzonitic wall-rock shows that the alteration produced by these solutions consists of metasomatic alteration of the ferro-magnesian minerals, of chloritization, sericitization and silicification.

In the course of this metasomatism, pyrite, chalcopyrite and pyrrhotite have been developed. This type of alteration resembles in its essential features that which Lindgren has shown to be characteristic of metasomatic processes in fissure-veins, and from the above facts in themselves, and in the light of his studies of similar alteration in various districts, it appears that the alteration was produced by heated aqueous solutions rich in K_2O.

5. *Immediate Causes of Deposition of Lode-Ores.*—The form of a fissure is generally considered to exert an important influence on deposition, on the general principle that irregularity in a fissure, resulting in alternately closed and open, or gaping, portions, tends to vary the temperature and pressure of solutions and their solvent power. According to this, the wider portions of a fissure should be occupied by larger ore-bodies. In several cases in Bingham the ore thinned in descent when the dip changed, so as to make a decided bend or knee in the fracture-zone, and lenses of ore in zones appeared to "form on the flats."

Two chemical factors seem to have exerted a strong influence upon the precipitation of the lode-ores; namely, calcareous composition and carbonaceous contents of wall-rocks. Ore-bodies in fissures are relatively much thicker between limestone than between quartzite and porphyry walls. Thus the same lode is found to expand laterally on passing from quartzite and porphyry into limestone. Many large lodes and many distinct miniature examples in various portions of the camp bear out the fact that calcareous walls strongly induce ore-deposition.

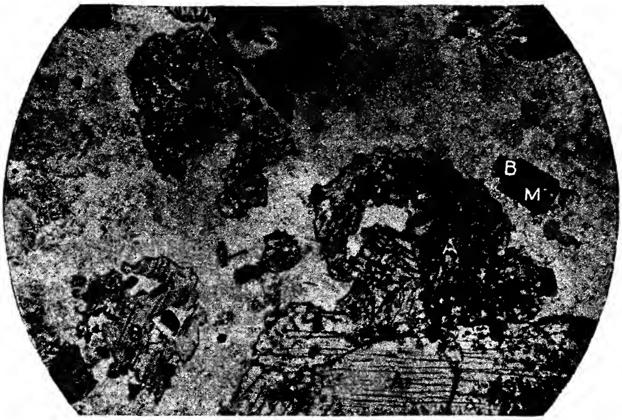

FIG. 2.—TYPICAL MONZONITE OF BINGHAM. (FROM TRIBUNE TUNNEL, TELEGRAPH MINE.) (SP. NO. 117 (47). WITH ANALYZER, x 48.)

Fine-grained, granular to subporphyritic structure. Augite (A), biotite (B) and orthoclase form chief constituents. The inclosing areas are almost entirely feldspathic, including both orthoclase and plagioclase, with a little garnet. Augite is slightly uralitized. The small black areas are nearly all magnetite, but a few are grains of pyrite.

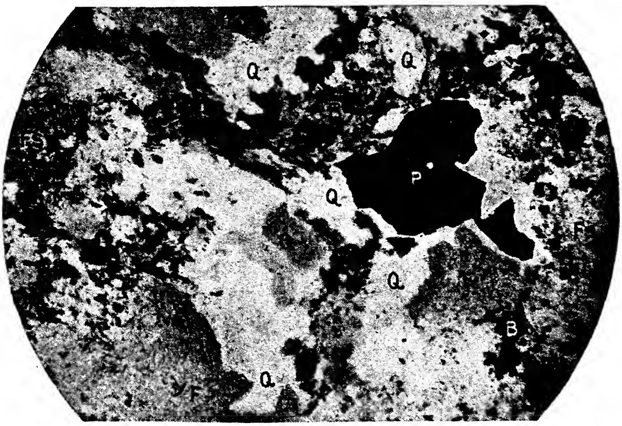

FIG. 3.—DEVELOPMENT OF PYRITE IN ALTERED MONZONITE. (FROM ELDORADO SHAFT, BOSTON CONSOLIDATED GROUP.) (SP. 173 (48D). WITH ANALYZER, x 48.)

Magnetite and original biotite are absent, and pyrite (P) appears embedded in secondary quartz (Q), associated with flocculent aggregates of biotite (B) (probably secondary). Feldspathic constituents have gone over to sericite (F).

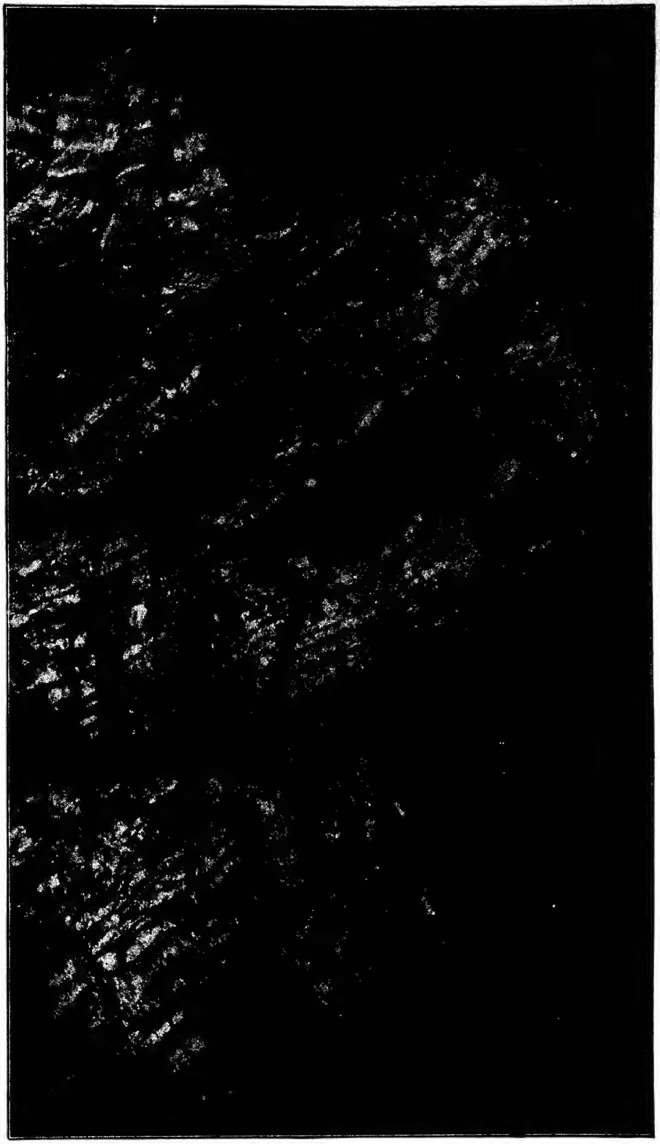

FIG. 6.—EARLY STAGE IN REPLACEMENT OF LIMESTONE BY COPPER-ORE. BANDED PARTIALLY MARMORIZED LIMESTONE CUT BY STRIKE-FISSURES. HIGHLAND BOY MINE, NO. 6 LEVEL, LOOKING WEST. In the walls of these fissures characteristic contact metamorphic minerals appear, and chalcopyrite and specularite replace metamorphic limestone.

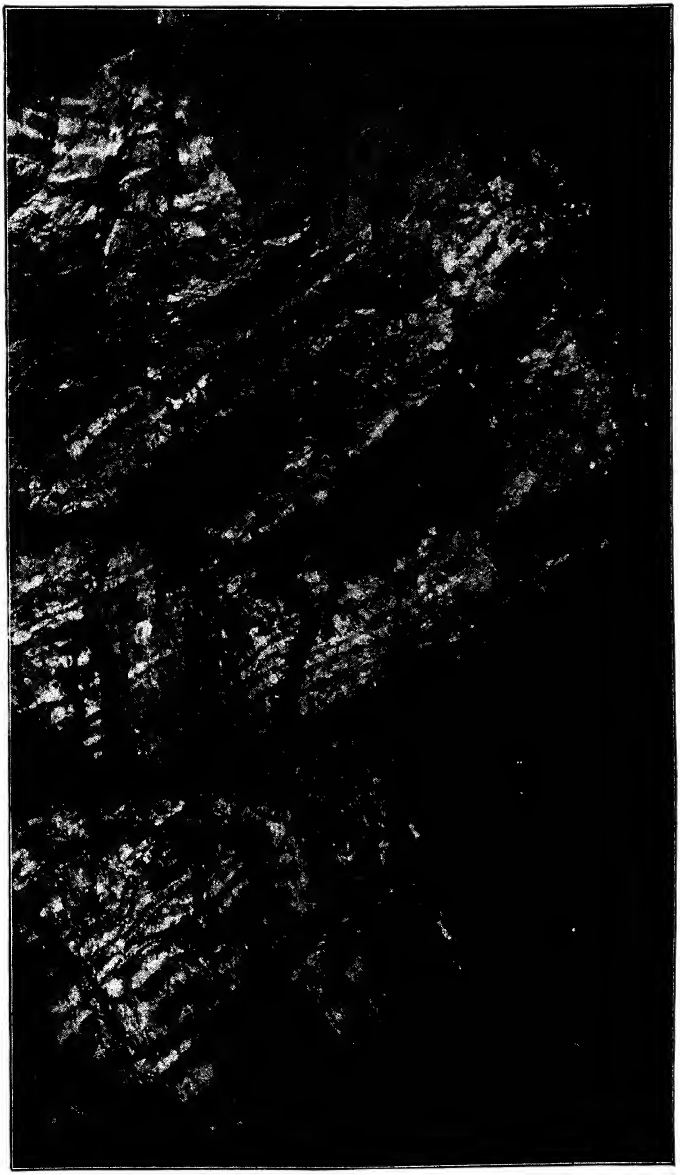

Fig. 6.—Early Stage in Replacement of Limestone by Copper-Ore. Banded Partially Marmorized Limestone Cut by Strike-Fissures. Highland Boy Mine, No. 6 Level, Looking West. In the walls of these fissures characteristic contact metamorphic minerals appear, and chalcopyrite and specularite replace metamorphic limestone.

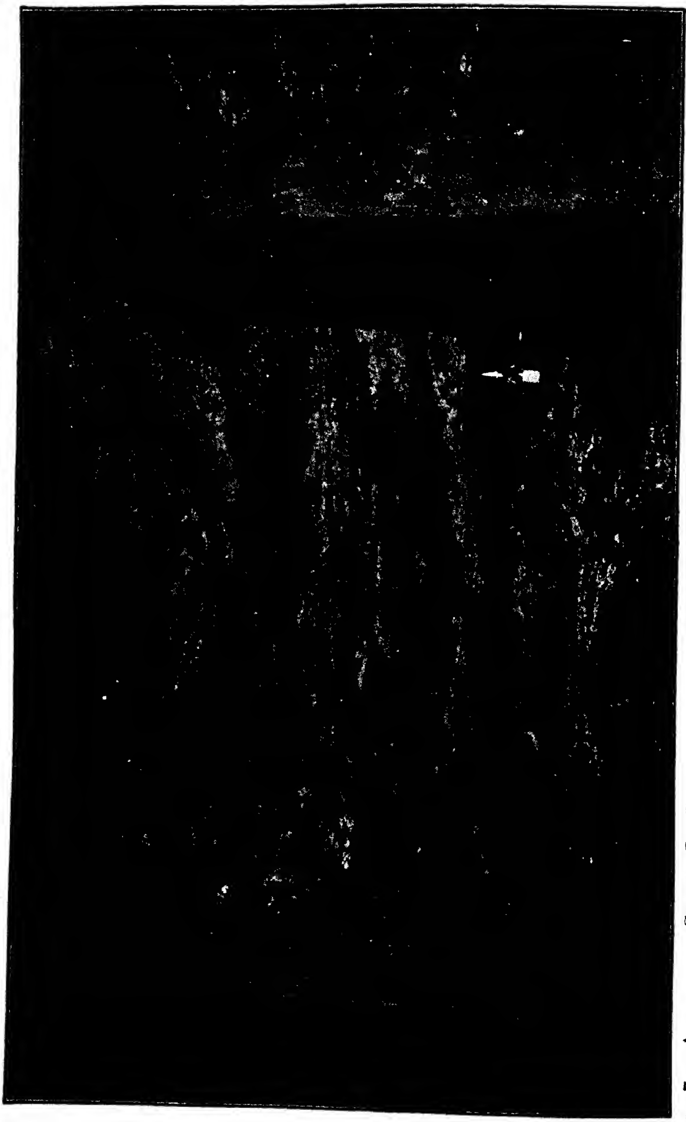

Fig. 7.—Advanced Stage in Replacement of Limestone by Copper-Ore. Telegraph Mine, Grecian Bend Level. The dark bands are chalcocite, chalcopyrite and pyrite, the light ones are granular quartz and cherty siliceous limestone. Retention of bedding-structure indicates replacement.

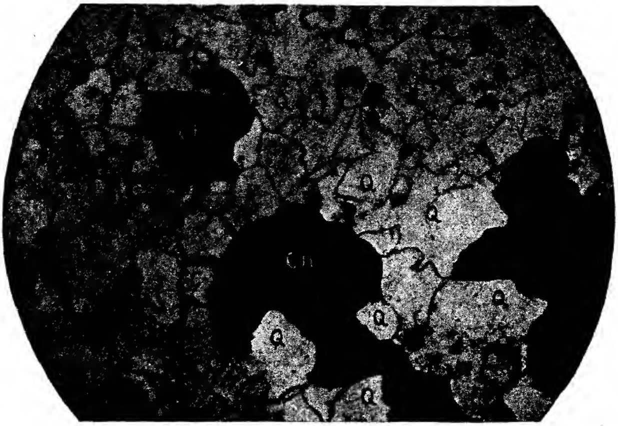

Fig. 8.—Chalcopyrite Developing in Marmorized Silicified Limestone. (Sp. H. B. 29; Without Analyzer, x 48 +.) From No. 1 Ore-Body, No. 6 Level, Highland Boy Mine.

Chalcopyrite (Ch) invading limestone metamorphosed to siliceous marble made up of granular calcite (C) and quartz (Q). Chalcopyrite replaces calcite and quartz.

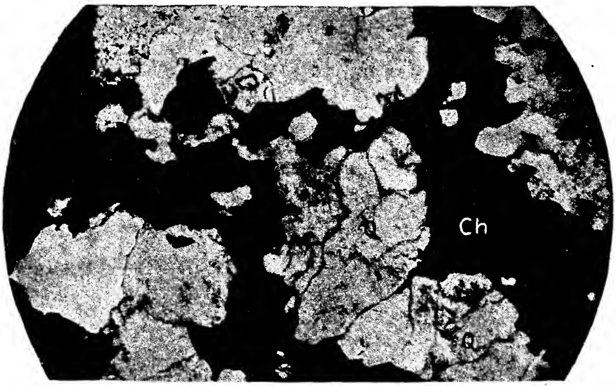

Fig. 9.—Intergrowth of Chalcopyrite and Pyrite Replacing Quartz. (Sp. No. 103b; Without Analyzer, x 48.) From No. 4 Level, Highland Boy Mine.

The chalcopyrite and pyrite (Ch) encircle and replace the quartz (Q) of an entirely silicified limestone. This section from a specimen from an upper level shows evidences of superficial alteration not apparent in the reproduction. The margins of the sulphide are tarnished, showing "peacock" ore.

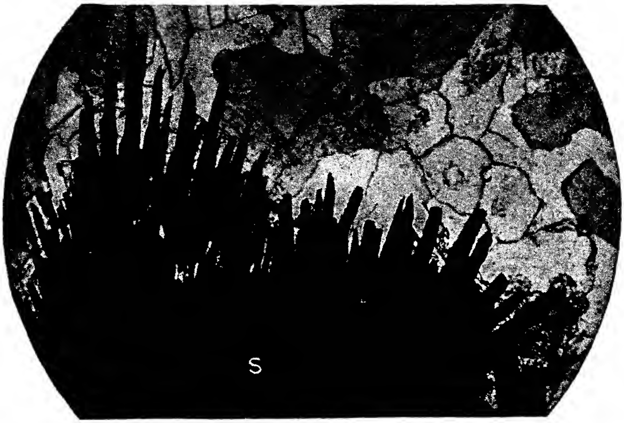

FIG. 10.—SPECULARITE REPLACING CALCITE. (SP. NO. 313; WITHOUT ANALYZER, x 66+.) FROM WALL OF E–W. FISSURE, WEST END NO. 6 LEVEL, HIGHLAND BOY MINE.

The black areas are foils of specularite (S) which replace calcite (C). The hand specimen from which this thin section was made shows chalcopyrite intergrown with specularite and replacing marble.

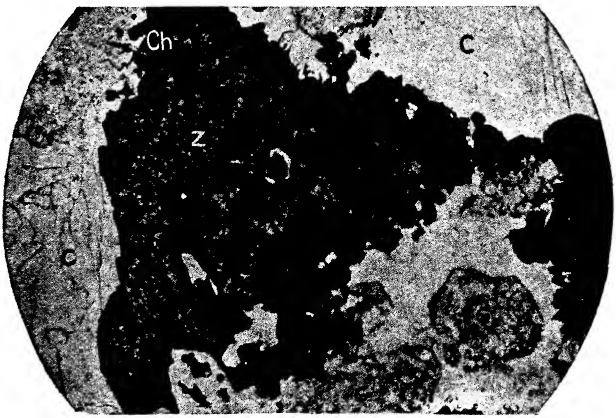

FIG. 11.—CHALCOPYRITE WITH ZINC BLENDE AND GARNET IN CALCITE. (SP. H. B. 16; WITHOUT ANALYZER, WITH CONVERGER, x 36.) FROM METAMORPHOSED LIMESTONE 60 FT. FROM MONZONITE INTRUSIVE, NO. 7 LEVEL, HIGHLAND BOY MINE.

The darkest areas (Ch) are intergrowths of chalcopyrite and pyrite. They fringe the zinc blende (Z) and are intergrown with it and green garnet (G). The groundmass is calcite (C).

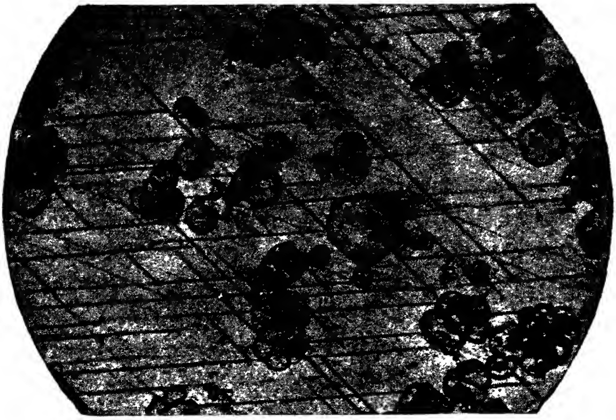

FIG. 12.—GREEN GARNET IN CALCITE. (SP. H. B. 16; WITHOUT ANALYZER, x 36.) FROM HIGHLAND BOY LIMESTONE, NO. 7 LEVEL, HIGHLAND BOY MINE, 60 FT. FROM MONZONITE INTRUSIVE.

Individual crystals and aggregates of crystals of green garnet in marmorized limestone.

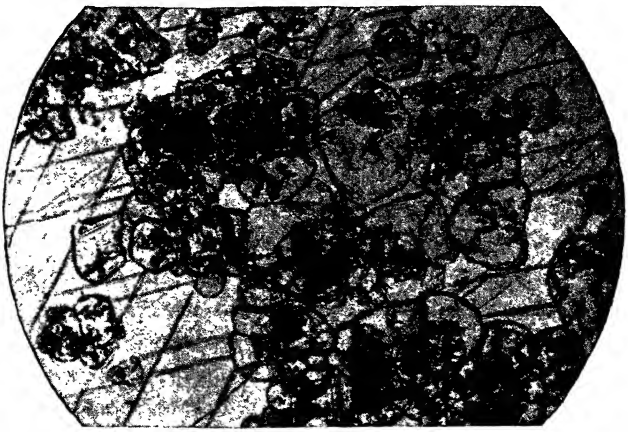

FIG. 13.—CHALCOPYRITE AND PYRITE ASSOCIATED WITH GREEN GARNET IN CALCITE. (SP. H. B. 16; WITHOUT ANALYZER, x 36.)

The darkest areas are chalcopyrite and pyrite grains intergrown with garnet. Near these crystals, just outside of this field, semi-crystalline masses of pyrite and irregular masses of chalcopyrite are developed in and around garnets and zinc-blende.

This factor is so commonly recognized that its extended consideration is unnecessary. The precise character of this influence could not be observed, as the ore-bodies have been so generally removed from the greater lodes. It is probable, however, that it was in large measure like that observed along the minor fissures; namely, metasomatic interchange through which ore replaced calcareous wall-rock.

Black shale, which contained calcareous and carbonaceous matter, also favored ore-deposition. Several fissures cut these thick massive shale-members interbedded in the quartzite in the upper portion of the Bingham section. Valuable ore-bodies occur in them in association with the black shale forming one or both walls. This is illustrated by the Erie vein, which is narrow between quartzite walls, and wide between shale walls; thus, in passing from quartzite into black shale, it changes from a lean seam from 6 to 10 in. wide to a rich shoot 12 ft. wide.

This shale varies from light-gray, dense, thin-bedded, calcareous sandstone to black, fine-grained, massive shale, and blue, compact, siliceous limestone. Thin sections of these shales under the microscope are seen to be made up of angular and sub-angular grains of quartz embedded in calcareous and black opaque amorphous matter, and the whole roughly bedded and cut by veinlets of calcite. Chemical analyses of four characteristic samples indicate that these shales are composed chiefly of SiO_2, Al_2O_3 and CaO, and in one instance considerable MgO. The evidence gained through microscopical and chemical examination thus accords in showing the shales to be essentially quartz, calcareous material and amorphous cement. Further, each of these rocks yielded upon analysis some organic material, probably mainly carbonaceous. Accordingly, the brownish-black amorphous matrix, which incloses the quartz grains and imparts to these rocks their dark color, is doubtless aluminous and carbonaceous matter. It therefore seems that the precipitating-power of these rocks is due to their content of CaO and MgO, together with organic matter mainly carbonaceous. Further, the structure of the rich argentiferous lead-ore in the Erie indicates that the process by which the metals were thus precipitated was replacement.

6. *Superficial Alteration.*—The argentiferous lead-ore in this district has undergone comparatively slight alteration. This

may be largely explained by the fact that galena is relatively stable under oxidizing agencies, and also that quartzite and intrusives, which are notably less favorable to oxidation than limestone, form in large measure the country-rock.

Galena occurs on the adit-levels of most of the fissure-mines in a practically unaltered state, and may be traced up even through the surface alteration-zone, characterized by "oxidized gold-ore" and carbonate copper-ore, to the present surface. In the early days, when the ore immediately below the surface was mined, a small amount of scattered sulphate and carbonate lead-ore appears to have been encountered.

The nature of this alteration is probably exemplified in a sample of silver-lead ore collected from an adit-level. This specimen exhibits five distinct stages of alteration as follows:

(1) The interior core consists of fresh, cleavable galena.

(2) A narrow band, of dull, dark-green to black color on conchoidal fracture, from 0.1 to 0.05 in. wide, marks the periphery of the galena, and extends into it along cracks and pits. On testing this alteration-product chemically it proves to be the lead sulphate, anglesite. It is quite probable that the color is imparted by a trace of copper which, existing as an impurity in the galena, is freed at this first stage of alteration, and then, owing to its ease of alteration, soon passes off. Slight traces of copper, remaining in the form of minute globules of malachite upon the surface, afford some basis for this explanation.

(3) Upon this dark band of sulphate rest thin, grayish-brown lamellæ, which give way to typical gray-brown anglesite in scattered, imperfect crystals with high luster.

(4) The carbonate, as proved by wet tests, occurs upon the surface of this sulphate.

(5) The oxide of lead, in the form of a finely granular, scaly, sulphur-yellow mineral of resinous luster, with streak lighter than color, has formed upon the surface. This may be massicot.

In short, then, the expectable changes resulting through oxidation are here seen in the passage from the sulphide through the sulphate and the carbonate to the oxide.

7. *Conclusion.*—In brief, it appears that heated, aqueous, mineral-bearing solutions rich in CO_2 and K_2O rose along strong NE–SW. fracture-zones, altered their walls by adding quartz to quartzite, impregnating marble with metallic sulphides and

specularite, and silicifying, sericitizing and impregnating monzonite with metallic sulphides, and deposited the lode-ores in largest volume between calcareous and carbonaceous walls, mainly by filling, partly by replacement; and that, subsequently, these primary sulphide-ores were changed by superficial alteration to sulphates, carbonates and oxides.

VII. *Genesis of the Copper-Ore in Limestone.*

1. *Character.*—These copper-ores, which constitute the bulk of the present output from this district and are thus responsible for its recent growth, have yielded most interesting and valuable data on their genesis. The character of these data, and the fact that they have led to conclusions which differ somewhat from current explanations, are the principal reasons for the preparation of the present paper.

The copper-ore in limestone is a massive pyritic ore composed essentially of sulphides of copper and iron. Chalcopyrite and pyrite form the bulk of the large ore-bodies, and are supplemented by relatively small amounts of chalcocite, tetrahedrite and tenorite. Other copper-bearing minerals found, are,—bornite, binnite, cubanite, enargite, tennantite, bournonite, covellite, cuprite, malachite, azurite, chalcanthite, pisanite and native copper. Quartz predominates in the gangue, and garnet, epidote, tremolite, specularite, pyrrhotite and sphalerite are present in small amounts. These pyritic ores also carry a little gold and silver and an appreciable amount of tellurium. In the enriched black sulphide-ores the amount of tellurium is largely increased, and gold and silver are present in very high values,—probably as tellurides.

2. *Occurrence.*—The large copper-ore bodies are restricted to thick massive limestones which have been subjected to extensive intrusion, intense metamorphism and profound fissuring. The ore occurs adjacent to the intrusives and to the fissures, and is intimately associated with contact-metamorphic minerals. It lies within these metamorphosed limestones along beds at one or more horizons. In form the ore-bodies are irregular lenticular beds, which thicken and thin locally, and terminate laterally along attenuated uneven margins.

In brief, the occurrence of the great copper-bodies, exclusively in those portions of the great limestones that are charac-

terized by pre-mineral fissures, requires that a satisfactory explanation shall recognize this constant and intimate association; and the occurrence of these copper-ores in the vicinity of intrusives within highly metamorphosed limestone in association with tremolite, garnet, epidote, specularite, pyrrhotite, etc., raises the query whether the contact-metamorphism thus indicated may not have also influenced the generation of the copper-ores. Accordingly one or both of these factors seems to have entered into the formation of this ore, and the explanation of their origin involves a critical examination of the facts with a view to determining the parts probably played by these two genetic processes: (1) deposition from solutions introduced through fissures, and (2) contact-metamorphism.

3. *Deposition.*—A knowledge of the nature of the process aids in determining the cause which led to deposition. The structure of the copper-ore and the occurrence of the ore-minerals afford conclusive evidence as to the process by which the ore was deposited. Evidence on these facts was found in such completeness that its somewhat full presentation seems especially warranted. It comprises the broad structural character of the shoots of copper-ore, the structure of hand-specimens of ore, and the occurrence and association of ore-minerals as shown in thin sections under the microscope.

The characteristic broad structure of the copper-ore in limestone is banded. This banding is not like the crustified or even the roughly-banded structure of the lodes, but is a bedding, which, in form, is identical with the bedding of the strata. The chief difference is in composition; these beds being composed of ore instead of barren country-rock. Bedded structure characterizes, alike, miniature ore-bodies, mineralized wall-rock adjacent to seams, and large lenticular ore-shoots. Further, the marked deposition of ore along certain beds, and the slight deposition along others, appear to indicate a selective tendency on the part of mineral in solution for more soluble beds. This selective action leads to a very irregular periphery. The transition from massive, solid ore is not sharp, but gradual, passing from rich copper sulphide through lean copper-ore, still poorer ore, then merely stained country-rock, to normal barren marble. Although the composition changes from ore to barren country-rock, the structure is persistent; so that a bed of ore is

clearly seen to be a portion of the same bed of country-rock; in other words, the ore has retained the bedded structure of its country-rock.

This may be observed in various stages. Thus, the earliest stages are seen where a small amount of ore has taken the place of metamorphosed limestone adjacent to fissures (Fig. 6); later stages where more and more ore has been deposited along the beds, until the greater part of the country-rock has been turned into ore, and the original bedding is preserved by bands of silica (Fig. 7), and, at last, the final stage in which practically the entire mass is ore, and only occasional irregular bands of granular quartz, and an indistinct differentiation of the massive sulphide-ore into beds of somewhat unlike types, indicate on a broad scale a bedded structure. Innumerable occurrences of this character leave no doubt as to the banded structure of the copper-ores.

Such features, especially bedding of ore, which corresponds to the stratification of the country-rock, are usually considered to signify that the ore has taken the place of the country-rock by substitution. They are characteristic of known replacement-deposits.

The general evidence thus afforded by the broad structure that the copper-deposits in limestone were formed by replacement, is supported by the detailed facts. Just as the massive beds of ore appear to replace massive beds of rock, so these beds of ore preserve the fine lamination of the country-rock. Thus, a hand-specimen shows copper- and lead-ore making, in bands in an impure semi-crystalline limestone, narrow seams composed of irregular grains of pyrite and chalcopyrite alternate with other thin layers composed of galena, fine-grained copper sulphide and alteration products of limestone. Such criteria, which may be seen on both large and small scale in the various mines, tend to increase the probability that the process of ore-deposition was one of replacement.

They hardly prove, however, that the metasomatic processes noted were "molecular processes involving simultaneous dissolution and precipitation on the one hand," or "previous dissolution and subsequent precipitation on the other."[7] For "the

[7] Lindgren, Waldemar, Metasomatic Processes in Fissure-Veins; *Genesis of Ore-Deposits* (1902), A. I. M. E., p. 515.

theory of the substitution of ore for rock is to be accepted only when there is definite evidence of pseudomorphic, molecular replacement."[8] Lindgren has held that the only thorough proof of such molecular replacement is that obtained by microscopic examination of the occurrence of individual ore-making minerals.

Microscopic study of thin sections of Bingham copper-ore affords abundant evidence of progressive stages of replacement of the calcareous country-rock by copper-bearing sulphides. These stages may be clearly made out in the order of their development as follows: (1) Calcareous ground-mass showing small, irregular quartz areas, which are occasionally separate, and occasionally associated with small grains and tongues of chalcopyrite; (2) coarse quartz and sulphides penetrating a calcareous ground-mass in small, isolated areas and in larger, irregular patches and sinuous veinlets; (3) complete extinction of calcareous ground-mass through replacement by coarse quartz and sulphides; (4) continued replacement by sulphides to extinction of all except occasional bands and isolated areas of granular quartz. (Figs. 5, 8 and 9.)

The process is thus seen to be characterized by a calcareous, partially calcitized ground-mass, penetrated by irregular areas of intimately associated granular quartz, pyrite and chalcopyrite, in which quartz replaces calcite, and grains of pyrite and chalcopyrite gradually grow along irregular margins into and replace grains of calcite and quartz.

In brief, the retention of stratification of the country-rock by banding in copper-shoots, and the banded structure of ore tend to show the deposition of copper-ore in limestone by replacement of the country-rock. The growth of secondary quartz, pyrite and chalcopyrite in calcite, as observed under the microscope, indicates that the deposition of copper-sulphide ore in limestone took place by molecular replacement.

4. *Relation of Fissures.*—Replacement of the limestone country-rock by copper-sulphide ore might have been induced in either of the two ways under consideration: (1) by entrance of mineral-laden solutions from fissures, or (2) by metamorphic action due to intrusions. The former possibility is the expla-

[8] Becker, G. F., Discussion of Genesis of Ore-Deposits by Posepny; *Genesis of Ore-Deposits* (1902), A. I. M. E., p. 205.

nation which is found generally current through the district, as it is held that contemporaneously with deposition of the lead-ore all the copper-ore entered the limestone from the fissures. Certain features might appear, on a cursory study, to favor this explanation; other facts tend rather to confirm a belief in contact-metamorphism.

The current idea is based upon the fact that the principal copper-bodies are either adjacent to, or apparently cut by, strong mineralized fractures, and upon the belief that the copper-ores are contemporaneous with the fissure-ores. The first point is a recognized fact; yet it is noteworthy that in the large number of occurrences studied, the physical connection of fissure-ore with the copper-shoots was not observed in a single case, and the fissures, with two exceptions, did not appear to be feeders for the copper-bodies. Further, the typical replacement ore in limestone is essentially a copper-ore, and the typical lode-ore is essentially a lead-silver ore. Thus the ore of the No. 1 shoot in the Highland Boy mine is a mixture of copper and iron sulphides with associated gold and silver in minor amounts, while the ore from the Silver Shield and Galena lodes is an argentiferous galena with some argentiferous tetrahedrite and a scattering of copper and iron sulphides. These two types of ore, the pyritous copper and the argentiferous lead, so far as known, have not been observed to grade one into the other, but are mineralogically distinct. Finally, as regards the relative date of deposition of these two types of ore, the lode-ore is later than the intrusive, and the replacement-ore, in part at least, is probably roughly contemporaneous with intrusion. The bulk of the replacement-ore was probably either contemporaneous with intrusion, or contemporaneous with the subsequent deposition of the lode-ore from later emanations from the deeper, still uncooled portion of the intrusives. Certainly not all of the replacement-ore was deposited simultaneously with the lode-ore.

These facts throw much reasonable doubt on the belief that all of the copper-ore was deposited in the limestone from solutions which ascended the lode-fissures. Search for conclusive evidence on certain critical points was unsuccessful. The evidence secured does not lead to the conclusion that strong fissures were the sole sources of the copper-bearing solutions.

5. *Relation of Intrusives.*—Ores formed directly through the agency of intrusives, that is, by contact-metamorphism, are commonly known as "contact-deposits." This phrase has been rather loosely applied to several types of ore-deposits, so that further definition is necessary in order to avoid ambiguity. Instances of two of these uses will suffice: (1) Valuable ore-bodies are known to occur in the lower portion of limestone at or near its contact with underlying quartzite. Such deposits are commonly termed by miners "contact-deposits." (2) Again, useful minerals, which in well-recognized instances constitute ore, are found in sedimentary rocks (especially in calcareous sediments) adjacent to intrusives. Such bodies have also been termed "contact-deposits." In this discussion the term "contact-deposits" will be applied only to ore-deposits occurring in metamorphosed sedimentary rocks (more especially limestone) at or within a short distance of an intrusive in association with typical contact-metamorphic minerals.

That the copper-ores of Bingham are causally related to the intrusives, and were thus generated by contact-metamorphism, is strongly suggested by their character and occurrence. The evidence as to the relations of the copper-ores to the intrusives includes their general distribution, their specific location, and their mineralogical association.

The large copper-deposits, as above noted, are restricted to metamorphosed limestone. It is sufficient for immediate purposes to know that a careful study of this metamorphism, with a view to determining whether it is regional or contact in origin; and, also, its character, has afforded significant conclusions. In brief, it was found that the metamorphism of the limestone shows no relationship to the broad dynamic features of the region, but is co-extensive with the intrusives, and thus is probably directly related to them. The general nature of this metamorphism of the limestone is silicification and marmorization, though its specific character varies greatly. Normal blue limestone is changed entirely to coarsely crystalline marble. In other examples the metamorphic product is banded siliceous marble, with nodules and frequently beds of vari-colored chert. Chemical examination shows that the alteration comprises an increase in silica and magnesia, and a decrease in calcium and carbon dioxide, or, in brief, that it is a metasomatism consist-

ing of silicification, dolomitization (?) and a partial decarbonization. The distribution and character of the metamorphism thus shows it to be contact-metamorphism.

Furthermore, thorough examination of the position of the bodies of copper-ore, with respect to bodies of intrusive rock, reveals a most striking propinquity. The copper-deposits not only lie within contact-metamorphosed limestones, and in the vicinity of intrusives, but they are invariably developed close to the intrusives.

Finally, this general evidence is entirely supported by the detailed evidence afforded by the character and mineralogical association of this ore and its gangue. Certain minerals, through their constant association in known deposits, have come to be recognized as indices to respective types of ore-deposits. "Ore-minerals" characteristic of contact-deposits are, "specularite, magnetite, bornite, chalcopyrite, pyrite, pyrrhotite, and, more rarely, galena and zinc-blende." "The gangue contains garnet, wollastonite, epidote, ilvaite (lievrite), amphibole, pyroxene, zoisite, vesuvianite, quartz and calcite; rarely flourite and barite." "The characteristic feature is the association of the oxides of iron with sulphides," . . . "and the presence of various silicates of lime, magnesia and iron."[9]

All of these characteristic ore-minerals occur in Bingham, associated with bodies of copper-ore in limestone, and a number of the gangue-minerals have been recognized. Specularite was found sparingly in float and plentifully in limestone adjacent to fissures of the great east-west fracture-zone (see Fig. 10). It is a finely cleavable variety that occurs in masses associated with magnetite, chalcopyrite and pyrite, and inclosed by bands of hematite. It also occurs in radiating foils mingled with chalcopyrite and pyrite, replacing calcareous wall-rock adjacent to minor fractures. In other cases it is in seams and crystalline flakes associated with the same minerals, and some galena and carbonates of calcium and magnesium. Small quantities of a magnetic black metallic mineral are intimately associated with specularite. No titanium was detected in this by wet test, and it is believed to be magnetite. Galena is found

[9] Lindgren, Waldemar, Character and Genesis of Certain Ore-Deposits; *Genesis of Ore-Deposits* (1902), A. I. M. E., p. 717.

with these minerals; also zinc-blende; both, however, in subordinate amounts. Pyrrhotite in massive form is disseminated through some of the copper-sulphide ore in intimate association with pyrite and chalcopyrite. Finally, pyrite (and especially chalcopyrite) is associated with these type-minerals in lean ore on the margins of ore-bodies adjacent to intrusives in the Highland Boy, and constitutes the bulk of the primary copper-ores.

Thus, a sample from the base of No. 1 shoot, No. 7 tunnel, Highland Boy mine, along the zone of transition from ore to barren marble, and adjacent to a cross-cutting sill, affords clear evidence on the association of chalcopyrite and garnet in marmorized limestone adjacent to intrusives. The development of pale brownish-green garnet in a ground-mass of calcite is seen, under the microscope, to proceed from small, rounded grains through larger semi-crystalline grains to well-formed crystals and aggregates of crystals (see Figs. 12 and 13). Intimately associated with these garnets are grains and irregular patches of chalcopyrite. Thus, grains of chalcopyrite appear at the core of garnet crystals, scattered through them, distributed along their margins, and also associated in a similar unsystematic manner with the aggregates and irregular areas of garnet. Occasionally, garnet appears inclosed by chalcopyrite. Clearly some of the garnet was formed after some of the chalcopyrite, and before other portions of chalcopyrite. It cannot be affirmed that some of the garnet and some of the chalcopyrite were not formed at distinct dates by different factors. The observed features tend rather to show, however, that the garnet and chalcopyrite are of contemporaneous origin. Again, zinc-blende occurs in irregular masses embedded in the calcite ground-mass, and fringed and penetrated by narrow irregular bands of chalcopyrite (Fig. 11).

A number of the other characteristic gangue-minerals have been detected. Secondary quartz and calcite are found associated with intrusives throughout the district. Greenish-yellow chlorite (a more unusual contact-mineral)[10] has been recognized in several places, especially in the fractured country adjacent to E–W. fissures in the western portion of the Highland

[10] Harker, A., *Petrology for Students*, 2d ed., 1897, p. 283.

Boy mine. It occurs in elongated lenticular areas associated with calcite, adjacent to a fissure within a shear-zone. Again, bands made up of small, irregular grains of chlorite traverse a granular ground-mass of calcite. Branching seams of chalcopyrite penetrate the chlorite along the contacts of these bands with the ground-mass. Plates of chlorite inclose grains of chalcopyrite in another occurrence. In another slide of a sample from the Highland Boy mine, sub-angular grains and medium-sized pieces of olivine occur, in some instances apparently passing into serpentine. Tremolite occurs in coarse marble in stellate aggregates of white, acicular crystals. A minute bit of an unproved mineral, somewhat resembling fluorite, was found in the Highland Boy; and large areas made up of bundles of fine, parallel acicular crystals or filaments occurring in marble are probably composed of the silicates that are typical of contact-metamorphism of limestone. Further study would doubtless lead to the discovery of other minerals characteristic of contact-metamorphism.

In brief, limitation of the productive ground in this district to the region of intrusives, extensive metamorphism of the limestone within this area due to contact influences, the restriction of the copper-shoots in limestone to areas of contact-metamorphism, the propinquity of these copper-ore bodies and the intrusive bodies, association of oxides of iron with the sulphides of copper, the content of some gold and silver in the sulphides, and the intimate association of gangue-minerals characteristic of contact-deposits with ore-minerals, clearly indicate a causal relationship between the intrusives and the deposition of the copper-ore.

The development of chalcopyrite in contact-metamorphic garnet, and its association with chlorite, pyrrhotite and specularite, prove that some of the copper-ore in limestone is a "contact-deposit."

It appears that the evidence obtained is insufficient to warrant the assignment of the origin of all the copper-ores in limestone to any single cause. That some of the copper-bearing solutions entered the limestone through the lode-fractures has not been disproved. Some facts show, however, that this was not the sole mode of deposition, and concrete evidence in favor of this process is lacking. Accordingly, the settlement of this portion

of the problem awaits conclusive evidence. On the other hand, a portion of the copper-ore has been found without doubt to have been immediately due to intrusives. The evidence is not yet sufficiently complete to prove it, but no facts have yet been found which are against the conclusion that all the copper-ore in limestone was formed through the influence of intrusives.

6. *Superficial Alteration.*—The complete sequence of the stages of alteration of the Bingham copper-ores in limestone was not found in connection with any single deposit. The properties which have been opened from the surface, through the several zones of alteration, to sulphides below water-level, have been abandoned in the older portions, or are caved. Each stage, however, was observed in some part of the district, and these separate items united afford the complete story.

The facts observed in Bingham show, in general, that carbonates, oxides and native copper occur at the surface; that these pass into secondary sulphides, which in turn give way to primary sulphides in depth. Thus, the surface portions of shoots of copper-iron ore in the large mines were made up of malachite and azurite and occasionally contained cuprite. These pass gradually into sulphides in depth. Cores of black sulphide occur within the green carbonate, and bands of carbonate-ore fork down into the sulphide, becoming narrower in depth, and finally thinning-out entirely, give way to sulphide.

Black sulphide, marking the zone of sulphide-enrichment, then constitutes the body of the copper-ore for a considerable distance in depth. This distance varies much, and, owing to deformation of country-rock and lack of development, it cannot be stated definitely. It may be said in a general way, however, that the thickness of the zone of oxides and carbonates is not so great as the thickness of the zone of black sulphides. The transition from the zone of oxidation to the zone of sulphide-enrichment is gradual. It is to be seen in its earliest stage in the slight enrichment along fractures in primary sulphides, in hand-specimens, and in thin sections showing various stages in its progress. Thin sections of rich copper-ore made up of black sulphides and chalcopyrite, from the West Emma and Coolidge stopes of Old Jordan mine, reveal details in the progress of this alteration. Massive, porous chalcopyrite in a quartz-gangue is seen to be traversed by many cracks.

Narrow bands of a grayish-black metallic mineral fringe the edges of chalcopyrite, penetrate the mass along these cracks, and even line the walls of interior spaces in the chalcopyrite. Although, in some instances, intergrowth is rather uncertainly suggested, in many places the black metal is clearly seen to have formed along cracks that were developed after the chalcopyrite had been deposited, and to replace the chalcopyrite.

An advanced stage in this replacement is indicated by a hand-specimen from the Commercial mine. Black sulphide-ore makes up the outer portions and yellow sulphide forms the inside portion, between the black sulphide. The boundaries between the two are not sharp, but the black gives way gradually to the yellow, sending finally only narrow stringers into the core. The black material is composed of chalcocite and tenorite, melaconite, probably some tetrahedrite, and tellurium with gold and silver. The yellow core is mainly granular pyrite. In brief, this is believed to show the replacement of a mass of primary sulphide by black copper sulphide.

In addition to affording evidence that the process of enrichment is molecular replacement, this sample also gives valuable information on the occurrence and transfer of values in secondary enrichment. Selected samples of the black sulphide and carefully-picked samples of the yellow sulphide were tested for their values by Dr. Hillebrand and Dr. Allen in the laboratories of the U. S. Geological Survey. The yellow, probably primary sulphide, yielded: gold, 0.1 oz.; silver, 3.32 oz.; a little copper, and a trace of tellurium. The black sulphides yielded: gold, 3.8 oz.; silver, 58.6 oz.; copper, 42.3 per cent., and a proportionately increased amount of tellurium. Dr. Hillebrand is of the opinion that, from the amount of tellurium present, it seems probable that the silver and gold both exist as tellurides. This goes to show that not only are the copper-values thus highly raised by enrichment, but that gold and silver, believed to occur as tellurides, are also proportionately enriched. The high ratio of values in the primary sulphide to those in the secondary also suggests that, if these added values were derived solely by robbing overlying low-grade primary ores, a large mass would have been required to afford such a large increase.

This enrichment may be observed to proceed gradually until, through the continued relative increase of the secondary sul-

phide and decrease of the primary, the entire mass of an ore-body is made up of high-grade, enriched, black, sulphide-ore. This constitutes the so-called "black sulphide" ore, which is the richest copper-ore in this camp. In its typical occurrence it is a loose, dry, dull, granular, black, earthy ore, intermingled with gray and grayish-black metallic scales and larger portions. This may frequently be seen inclosing cores of yellow sulphide and intimately associated with chalcopyrite and pyrite. Although this black ore varies in character somewhat, it is found, on chemical examination of selected samples from several mines, to consist chiefly of chalcocite (black copper sulphide), tenorite (black copper oxide), melaconite (massive earthy variety of the copper oxide, tenorite), some tetrahedrite, and probably some enargite.

Below this zone of sulphide enrichment, low-grade cupriferous pyrite occurs. The passage out of this zone in depth, like the entrance into it, is gradual. Within the body of rich black ore, nodules and grains of cupriferous pyrite occur which, in depth, become more numerous and pass into continuous bands which lead to the primary sulphides. The transition from secondary to primary sulphides, begun in this way, progresses by continued decrease of secondary and reciprocal increase of primary sulphides.

The above descriptions present the facts of superficial alteration, including sulphide enrichment, observed in Bingham. It is believed they compose an accordant sequence. In brief, the copper-ore was apparently deposited originally in metamorphosed limestone in the form of the sulphides, pyrite and chalcopyrite. Surface water, containing free oxygen, descending through limestone doubtless became carbonated, and, in certain instances in percolating through intrusives, probably took up some of the component alkalies. The oxidation of the cupriferous sulphides by such carbonated waters would have produced carbonates and oxides of copper. Reduction of these compounds would yield native copper. Beyond this stage, oxidation having ceased and reduction alone characterizing the alteration, secondary sulphides would have formed. Below the downward limit of the formation of secondary sulphides the primary sulphides would remain in their unaltered original state.

7. *Conclusion.*—The general features of the parts which ascending solutions from fissures and intrusives played in the formation of the copper-ore in limestone are clear, although the precise share which each took is not fully determined. In general, it appears that the principal source of the copper-ore in limestone was the magma of the intrusive; that the mineral elements were transported by the intrusives and by thermal solutions and vapors emitted first from their superficial portions, and at a later date from their deeper portions; that ore was deposited by molecular replacement of a metamorphosed, at least partly silicified, country-rock; and that the ores have since been changed in their surface portions by normal superficial alteration into sulphates, carbonates, oxides, and native copper.

VIII. *Periods of Ore-Deposition.*

Two periods of mineralization appear to be indicated by the general occurrence of the ores, but absolute proof is lacking. The occurrence of chalcopyrite and pyrite, intergrown with contact-metamorphic minerals adjacent to intrusives on the border of the largest body of copper-ore in the district, signifies that some of the copper-ore was formed by contact-metamorphic action at the date of intrusion. The argentiferous lead-ores, however, occur in fissures that traverse the intrusives; accordingly, they were formed after the intrusion. No means of fixing this later date of mineralization has been found; it may have been immediately after the intrusive had cooled to sufficient hardness to allow distinct fissuring. In this case it may be conceived as a later effect or consequence of the intrusion. Or it might have been deposited contemporaneously with the extrusion of andesite, which is believed to have occurred considerably later than the intrusion. The absence of metallic values in the extrusive, so far as known, is unfavorable to the hypothesis that the vein- and lode-ores are contemporaneous with extrusion. It thus appears probable that the vein- and lode-ores were formed subsequent to the date of intrusion—perhaps by after-action. The continuation of bands of lead-ore out from a fissure along beds of limestone, as observed in the Neptune mine, and similarly of cupriferous pyrite, as observed in the Colorado mine, seems to indicate that some of the ore in limestones, copper as well as

argentiferous lead, was not formed until the second period of mineralization.

In short, the ores of Bingham were probably deposited during two main periods of mineralization, some of the pyritic copper-ore being developed contemporaneously with intrusion, and the argentiferous lead-ores and the remainder of the copper-ore being deposited later—possibly by after-action.

IX. *Dates of Mineralization.*

The date or dates when ore-deposition took place have not been closely fixed. The special difficulty in determining the date of ore-deposition arises from the fact that only a small part of the geologic history—that recorded by a portion of a single formation—can be read within this area, and that this part cannot be precisely correlated with any part of the record of neighboring areas the geologic history of which is known, because this region is separated from them by extensive Quaternary deposits. Time-limits can be determined, then, only by broad and correspondingly uncertain correlations.

Dates of periods of mineralization are commonly fixed with reference to geologic events of known geologic date. The principal ore-bodies at Bingham, which occur in sediments, lie entirely within rocks of upper Carboniferous (Pennsylvanian) age. It is known that ore-deposition took place after the deposition of upper Carboniferous sediments, after the epoch of intrusion, and after the formation of NE–SW. fissures. On the other limit it is known that ore-deposition took place before fissuring in NW–SE. directions and secondary movement on NE–SW. fissures. Further, although definite evidence could not be found to prove the age of the NE–SW. and NW–SE. fissures and of ore-deposition as related to that of the epoch of extrusion, it seems probable that ore was deposited long before extrusion occurred. If the period of extrusion in this region was contemporaneous with that of similar extrusions between the Wasatch and Uinta ranges, it took place after Vermilion Creek Tertiary time. On the other limit, the period of intrusion took place later than upper Carboniferous time. According to the closest approximation it is now possible to make by such necessarily broad and uncertain correla-

tions, the ore at Bingham was deposited between upper Carboniferous and Vermilion Creek Tertiary times.

X. *General Conclusions.*

Between Carboniferous and late Tertiary time, monzonitic intrusives invaded sediments in the Bingham area, metamorphosed them, and introduced metallic elements which replaced marbleized limestone with pyritous copper sulphides. After the superficial portions of the intrusives had cooled to at least partial rigidity, they and the inclosing sediments were rent by persistent NE–SW. (and some E–W.) fissures.

Heated aqueous solutions from the deeper unconsolidated portions of the magma then ascended these channels, altered their walls, and introduced additional metallic elements. At this time more pyritous copper sulphide may have been added to that formed earlier in the limestone in connection with contact-metamorphism. Monzonite, including its original metallic constituents, was altered; copper, gold and sulphur were probably added, and auriferous copper sulphides were formed. The silver-lead ore was deposited in the NE–SW. fissures, mainly by filling, partly by replacement.

Since this second period of mineralization these original sulphide-ores have been altered by surface waters, in their upper portions into carbonates and oxides, and relatively enriched in their underlying portions through replacement by black copper sulphides.

The Origin of Vein-Filled Openings in Southeastern Alaska.*

BY ARTHUR C. SPENCER, WASHINGTON, D. C

(Washington Meeting, May, 1905)

In extension of a suggestion already made to account for certain features observed in the Juneau gold-belt in southeastern Alaska,[1] it is the object of the present paper to indicate in detail certain conditions in which deformation of rocks under their own weight might lead to the production of fractures in which veins could be deposited.

A direct, uniformly-distributed pressure of sufficient intensity, applied to an elastic brittle mass offering strong resistance to deformation, produces rupture. In a material of ideal properties the surfaces of rupture under such pressure would be shearing planes inclined at 45° to the line of force, unless there be preliminary deformation, in which case this angle would be greater than 45°. This general conclusion, resting upon analytical mechanics, is completely supported by the results obtained by Daubrée[2] in experiments upon the deformation of wax and resin prisms under compression. Let us then first consider one of Daubrée's diagrams. In the case illustrated in Fig. 1, four sets of fractures in two approximately right-angled pairs (that is to say, in conjugate sets) were produced by endwise compression of a square cross-sectioned prism. These fractures cut the axis of compression at approximately equal angles, not varying greatly from 45°. The location of the four sets of fractures is obviously determined by the shape of the prism, since the material in each corner acts in a way as a buttress, permitting the bulging to take place most readily on the sides. By limiting the directions in which bulging may take place, results of a more simple nature could be obtained. Take, for instance, a square prism, and place it between two fixed and

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[1] Geology of the Treadwell Ore-Deposits, *Trans.*, xxxv , 507, 508.

[2] *Études Synthétique de Géologie Expérimentale,* p. 316 (1879).

rigid walls. Under end-wise pressure, deformation can take place only by bulging out upon the two free surfaces. It is apparent, then, that under these conditions rupture will occur along only two sets of fractures, as shown in Fig. 2, and, as in the first case, the fractures will be symmetrically disposed in reference to the axis of pressure.

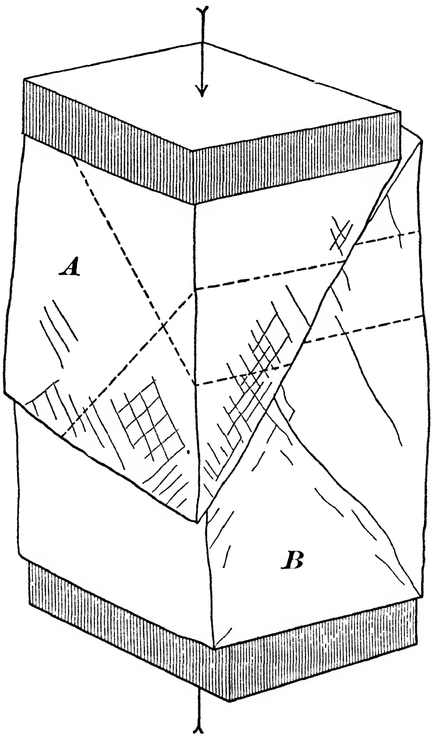

FIG. 1.—ILLUSTRATING DAUBRÉE'S EXPERIMENT, IN WHICH FOUR SETS OF FRACTURES IN CONJUGATE PAIRS ARE DEVELOPED. THE FRACTURES WHICH INTERSECT ON *A* ARE PARALLEL ON *B*, AND VICE VERSA.

In an ideal material, as before stated, the fractures produced by compression will intersect the axis of pressure at an angle of 45°. Suppose that in such an ideal material two sets of fractures showing conjugate relations are found, but that differential motion has not taken place or cannot be determined by inspection of the fractured surfaces. It is evident that observation will not lead to establishing the direction in which the rupturing force was applied because there are two possible

axes from which to choose. Thus, in Fig. 3, the compression causing rupture on *aa* and *a'a'* may have been applied along *HH* or along *VV*.

Considering fractures in nature, the foregoing deductions may be applied in a general way without taking up the modification in the angles between fractures, due to non-homoge-

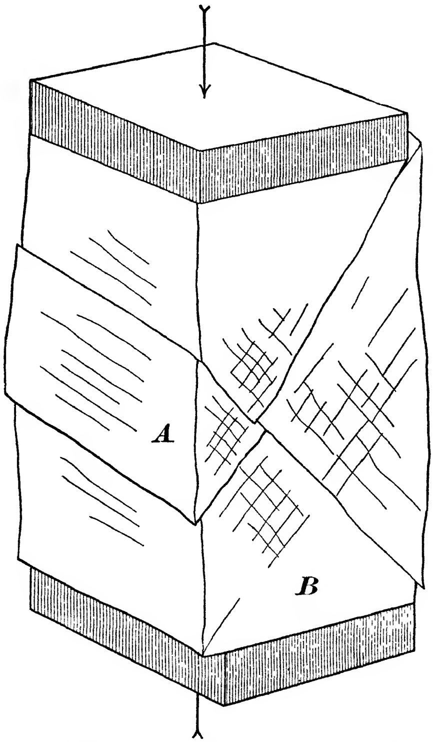

Fig. 2.—Fracture in a Square Prism Restrained on Two Opposite Sides, *B*, but Free to Deform on the Remaining Side, *A* Result. Two Sets of Fractures in Conjugate Relation.

neity and lack of perfect elasticity in the rocks, or to preliminary deformation by cubic compression.

For a case of comparative simplicity, it may be imagined that a block of the lithosphere is moved out of its place in a direction opposed to gravity, or, what amounts to the same thing, the surrounding rocks may be supposed to have been drawn away from any block. By such an adjustment of masses, equilibrium in the blocks is disturbed, and, because the

restraint of the neighboring masses has been removed, there will be a tendency for the block, which is differentially raised, to flatten out under the action of gravity. In deformation under these conditions the weight of the block takes the place of an outside force which is commonly called upon in accounting for fractures observed in the rocks. If the sides of the raised block are unrestrained to a sufficient depth, depending upon the strength of the materials involved, the flattening must take place in order to restore equilibrium within the mass. This case is analogous to the deformation or rupture of a column of granite or marble in the ordinary crushing test of the laboratory. In both cases, as in the experiments of Daubrée, strain beyond the ultimate strength of the material will result

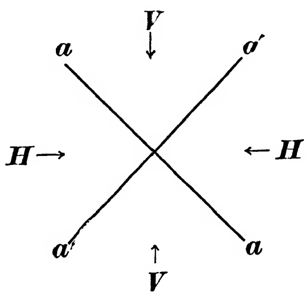

FIG. 3 —ILLUSTRATING THE TWO POSSIBLE AXES OF PRESSURE IN THE CASE OF CONJUGATE FRACTURES—*H H*, *V V*, FORCES; *a a*, *a′ a′*, FRACTURES

in fractures due to shear, and these fractures will occur in sets equally inclined to the axis of pressure. If the block were a cylinder free to deform in any direction, fractures would be equally liable to open in all azimuths, and out of an indefinitely large number of possible rupture-surfaces those actually developed would be determined by fortuitous conditions.

On the other hand, it may be granted that in a block of any shape, restraint on certain sides would tend to reduce the number of fractures, and in the simple case of a long block with nearly parallel sides which had been moved differentially to a position above the neighboring blocks, or from which the pressure has been relieved on two sides, the tendency would be the production of two sets of fractures striking parallel with the

axis of the block and with opposite dips equally inclined to the direction of gravity.

In the case above stated, the direct or effective cause of the fractures would be gravity, though the ultimate cause would reside in the forces bringing about the postulated movement of the several earth-blocks. Likewise in any real case, though the two forces would necessarily act together and not separately, gravity would still be the efficient factor, since compressive shear would not result from a simple uplifting movement, without the resistance due to the weight of a mass of rock sufficient to produce rupture alone.

It is probable that fissures, produced in this way, would so closely resemble others developed under horizontal thrust normal to the long axis of the block, that only the most careful observation would furnish data for discrimination between them. In the case of vertical pressure, the phenomena of displacement and differential movement would be those compatible with vertical shortening and extension across any horizontal surface, while lateral pressure would induce vertical extension and horizontal shortening. That is to say, in the first case normal faulting would be expected, and in the second case abnormal or thrust faulting.

The particular case which has been deduced corresponds with the tectonic features which exist in southeastern Alaska, where a broad mountainous zone, lying between the plateau region of the interior and the submerged plateau which borders the Pacific, rises about 5,000 ft. above the former and no less than 15,000 ft. above the latter. Standing so far above the neighboring earth-blocks, it seems that in this great orographic mass there must even now exist a tendency to bulge toward the unrestrained sides. If so, conditions are favorable for the opening of fractures at a depth dependent upon the crushing strength of the rocks which compose the great mountainous mass.

The region is one of metalliferous veins, and it is found that a very large number of vein-openings fall into two sets having a common strike nearly parallel with the NW–SE. axis of the orographic block, and opposite dips at about equal angles with the vertical. While the actual dips vary from place to place, and the angle between the two sets is not

always the same in places where both of them are observed, they approach as closely to conjugate relations as could be expected in nature.

It must be supposed, as Dr. Becker has suggested in his description of the Treadwell ore-deposit,[3] that these fractures were caused by compressive strain. The additional suggestion made by him that the effecting pressure was applied laterally in a NE–SW. direction seems less acceptable with the foregoing discussion of possibilities in mind. I failed, however, while in the field, to establish any observational basis for deciding the actual direction of the forces, though I am by no means satisfied that the point cannot be settled by more critical studies than those which have been made. Dr. Becker's statement, that in the vicinity of Juneau the faulting on the fractures occupied by the veins is normal, is to be noted as favoring the vertical direction of the force causing fracture, provided that both rupture and faulting are attributed to the same date and the same general movement in the earth's crust.

If the observed vein-openings were formed in the manner here suggested, their production would have been the result of an ancient differential movement quite similar to that by which the present Coast Range is believed to have been raised above the interior plateau and the floor of the Pacific ocean.[4] In other words, the same processes, which have resulted in the existing tectonic features of southeastern Alaska, would have been sufficient, at an earlier period, to produce the phenomena which it is desired to explain. On the uniformitarian principle, therefore, the hypothesis which has been developed is *a priori* an acceptable one.

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[3] *18th Annual Report, U S. Geological Survey*, Pt. III., p. 67 (1896–97)

[4] The Pacific Mountain System in British Columbia and Alaska, *Bulletin of the Geological Society of America*, vol. xiv , pp. 117–132 (1903).

The Origin of Clinton Red Fossil-Ore in Lookout Mountain, Alabama.

BY WILLIAM M. BOWRON, CHATTANOOGA, TENN

(British Columbia Meeting, July, 1905)

THIRTY years ago, when I stood on the cliff of red fossil iron-ore, on Red mountain, Jefferson county, Ala., I asked what were the geological relations of this remarkable deposit. In reply I was told that it was a limestone, colored and saturated by some unknown but wholly external influences, and that at a reasonable distance from the surface the color would disappear.

I could find no satisfactory explanation, either of the nature of this wonderful external permeating influence, or of the cause of such a ferrous impregnation selecting this one particular bed of limestone, to the exclusion of the higher and lower beds of the same material which are not even stained.

I. THE PRESENT THEORY.

Referring to this subject, Dana says:[1]

> "The clays, clayey sandstones and limestones of the Clinton epoch, through New York and the Appalachians, show that the mud-flats and sand-banks, and hence the shallow seas of the coast region, still continued. . . . The beds of argillaceous iron-ore, which spread so widely through New York and some of the other States, west and south, could not have been formed in an open sea; for clayey iron-deposits do not accumulate under such circumstances. They are proof of extensive marshes, and, therefore, of land near the sea-level. The fragments of crinoids and shells found in these beds are evidence that they were, in part at least, salt-water marshes, and that the tides sometimes reached them."

At first, this explanation seemed satisfactory, but the more I studied the ore the less satisfying the explanation became.

1. In the ore itself, I found associated with the small particles of rounded matter (now consisting of iron oxide in which organic structure, if ever present, has become lost, though the

[1] *Manual of Geology*, 2d ed. (1875), p. 231

general shape is often strongly suggestive of *foraminifera, ostracodids*, and the minute calcareous organisms which have contributed their skeletons to the limestones of the world), an assortment of *brachiopods*, so varied as to give evidence of a large feeding-ground. These species, anchored when mature, feed on the minute life which, in turn, feeds on the sub-aqueous growth that is possible in shallow water only. Iron-water would have introduced conditions fatal to such plants and animals.

2. Apart from single shells, which might have been brought by tides or washed in over a circumscribing bar that would have rendered swamp-conditions possible, I found a fairly large colony of a *brachiopod*, which, like the mussels (*mytilus edulis*) that cluster round the dock-gates and posts of our seaports, had the habit of crowding in family groups till even the shells were distorted by such close proximity,—hence their specific name, *stricklandinia deformis*.

3. I found, also imbedded in the red ore, a portion of a reef-coral as pure and white as when secreted in the clear and well-aerated waters of the Paleozoic ocean.

4. On a base of a mud-parting I found the whirl of terminal "*cirri*" that form the root of one of those fixed *crinoids*, the bead-like joints of whose flexible stem are so familiar among the distinguishable remains that go to make up the bulk of the ore.

Dana says of the Upper Silurian :[2]

> "There is no evidence that the climate of America included frigid winds or seas. The living species in the waters between the parallels of 30° and 45° were in part the same with, or closely related to, those that flourished between the parallels of 65° and 80°. From this life-thermometer we learn only of warm or temperate seas."

The foregoing evidence shows: that there was a large and flourishing life-growth of the usual types common to warm shallow seas; that corals of types requiring free access of currents of sea-water were common; and, lastly, that very little difference in temperature existed between the parallels of 30° and 80°, a condition which can only be accounted for by an oceanic current of sufficient bulk and constancy to neutralize climatic differences.

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[2] Dana, *Manual of Geology*, 2d ed. (1875), p. 253.

The whole argument is fatal to the swamp-theory. I saw this objection, and appealed for information to those whose opportunities to study the ore had been greater than my own; but I was told that nothing was known definitely about it. I then began to gather the evidence in the case and found, at the outset, that only one inquiry would lead anywhere, and that was "How was the ore formed in this particular place?" A general scheme involved too many unknown local quantities, which, if assumed instead of being "observed," might introduce error into the hypothesis.

I also carefully examined all geological publications on the subject that I was able to find.

The most interesting paper[3] includes a description of fossiliferous iron-ore from Rochester, N. Y., by J. S. Diller, which is specially valuable, since it shows the views held by geologists who have had exceptionally favorable opportunities for studying the whole evidence. Mr. Diller says in part (pp. 138, 139, 140):

"The ore is usually fossiliferous, as is specimen 52, and is sometimes called 'red fossil-ore' At other times it is oolitic, and is referred to as the oolitic iron-ore; also as the Clinton ore, on account of its age and place of best exposure. The fossils are chiefly broken *crinoids* and *bryozoa*

"The rock is made up of flattish or elongated grains, many of which are fragments of shells, but when seen in the hand-specimen all appear to be oxide of iron. Under the microscope, however, these fossil fragments are, in most cases, found to be only partially made up of iron-ore. . . . Some of the grains look oolitic, but in a thin section, no concentric or radial arrangement, suggesting concretionary structure, was observed. At many other places, however, as shown by Smyth, the oolithic structure is well developed. . . . The silica (*binding the grains together*—W M. B) is occasionally radial-fibrous and optically negative, like chalcedony. . . .

"The fossiliferous and bedded character of this ore, and its extensive distribution, are altogether exceptional, so that its origin is a matter of much interest. James Hall regarded it as derived from pyrite, in part at least, through the action of thermal waters, but this view has long since given place to other hypotheses. . . .

"The oolitic structure of the ore, as shown by Newberry, favors the view which regards the ore as an original deposit instead of a subsequent replacement of the limestone."

C. Willard Hayes has recently examined many of the Clinton iron-ore mines of Tennessee, Georgia and Alabama with special reference to data concerning the origin of the ore; and he

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[3] "Educational Series of Rock-Specimens Collected and Distributed by the U. S. Geological Survey," *Bulletin No.* 150, *U S. Geological Survey* (1898).

reports that he has never found it passing into a non-ferruginous limestone. He also says: "While it is true that the proportion of iron to lime in the unweathered ore varies in some cases rather rapidly, it is quite as apt to vary along the strike as upon the dip, showing that the variation is original and not connected with depth below the surface." His observations lead him to conclude, as did Newberry and Smyth, that the iron-ore is an original constituent of the bed, and not due to later replacement.

These statements though conclusive, as far as they go, only transfer the question further, leaving still unsolved the problem of the origin of the ore.

II. Personal Investigation.

For ten years, or so, I had daily opportunities of seeing about 10 freshly-mined car-loads of the lean ore from Inman, Tenn. I became interested in the fossils, and, among others, I collected the following from the ore:

Merista nitida,	* *Diphyphyllum multicaulis,*
Stricklandinia deformis,	*Favosites favosus,*
Rhynchonella neglecta,	*Zaphrentis, various species,*
Pentamerus oblongus,	** *Fenestella Sp.? Near Stellatum,*
Strophomena rhomboidalis,	*Rensselaeria ovoides,*
Rhynchonella cuneata,	*Spirifer radiatus?*
Atrypa reticularis,	*Rhynchonella whitii,*
Choenetes Sp.?	*Dalmanites Sp.?*
Orthis elegantula,	*Calymene Blumenbachia,*
Orthis fissiplica,	*Platyostoma Sp ?*

* This is absolutely iron oxide, a colony of several square feet. Will the advocates of original deposition say that the coral was secreted as iron?

** This is pure white, is surrounded by red ore, and has no red particles mechanically held in its texture.

One peculiarity soon developed itself. In some of the leaner ore, and contrary to Mr. Hayes' experience, I found it in all gradations of iron-content, from absolutely pure limestone material to that in which the iron was of almost theoretical composition. Moreover, I took chips of very lean ore, and, omitting the usual laboratory crushing, I put a handful of the chips in a suitable vessel and left it for a week or so covered with dilute hydrochloric acid, which formed a supernatant iron solution

(subsequently decanted), and a mud. This mud was boiled with strong hydrochloric acid and potassium chlorate, which dissolved the alumina and left a greyish residue consisting mainly of silica, some of it being in the familiar gelatinous condition suggesting its having been present either as chalcedony or as a constituent of a silicate. On removing the silica by a solution of sodium hydrate, sand was left, a result which I was seeking. This sand was distinctly water-worn, thus showing, not the "gentle trituration" quoted by Dana as "evident," but the thunderous dash of waves against rocks whereon the corals flourished; and be it noted that in the South Pacific I have always found the corals thickest on the windward side of the islands, where the surf was heaviest, a result doubtless due to the greater aëration of the water.

In trying to remove some of the larger shells I had the usual experience of beginners in paleontology, and broke my best specimens. In some cases I found that, although the surrounding rock was red and the porous *brachiopod* shell pink, the interior cast was white. I had never heard of the theory that the iron-ore was an original deposit. The "external saturation" theory was supposed to be all-sufficient in those days.

The divergence between the story told by the ore and the explanation usually accepted, became so great that I extended my study of the subject. Dana's account of salt swamps seemed to be a misfit as applied to our local conditions; and such other references as could be gained from scientific papers fell far short of accounting for the presence and conditions of the Clinton red fossil-ore.

I gradually began an attempt to ascertain the geological and paleontological conditions under which the deposit was formed. Deposits are, at best, epitomes of the surrounding conditions. Conversely, if the surrounding conditions are correctly ascertained, there is a probability of some truth in a theory of the consequent deposit. This was my line of reasoning, and I give it at length, because when a worker takes a position opposed to those advocated by geologists of the highest rank, such as I have quoted, he is not entitled to a hearing unless he demonstrates each step of his theory. I believe that the ore was originally limestone and that its replacement has been the necessary consequence of well-recognized geological laws.

There had always appeared to me a weak spot in the "original deposit" idea, which has furnished the following conflicting "evidence:" It was not ŏolitic; it was ŏolitic; it was of organic origin; it was not of organic origin.

No geologist even guessed the source of a quantity so immense that it would sheet several thousand square miles. The question of its condition during transportation, or its place of abode during previous geological time, were not even hinted at.

According to my observation all the above-quoted statements regarding the granules of ore are correct. The same surf that rolled the sand grains into a limestone-forming bottom, washed coral and shell fragments, gravel, limestone, mud and fragments into the deeper water where the corals grew, allowing these substances to subside. Moreover, the quantity of water was so large that mud would not interfere with life, or storms introduce the false bedding that shallow waters show; a condition indicated by the presence of ripple-marks, which do not denote shallowness so much as they do the currents that swept these areas. This mixture of gravel, coral, comminuted shells, dead shells, mud—mostly calcareous, in part and derived from the vast areas of Silurian limestones, became the present ore-bed.

The iron came from the decomposition of pyrite, but not by means of thermal waters, as Hall has stated. The conditions by which this change has been wrought were and are continuous. There is no hard and fast line in nature; geology and physical geography are inseparable; and a brief statement of the dynamic and structural conditions which caused the coquina-like limestone to be converted into commercial iron-ore is necessary for an understanding of the subject.

III. Resulting Facts and Views.

The results that I have found are as follows:—

The Appalachian Era.

First Stage.—An archipelago, now the Blue Ridge mountains, west of which was an ocean of deposition; this stage corresponding to Lower Silurian time.

Second Stage.—A ridge extending SE. from Nova Scotia partly divides the Gulf Stream. The main body flows through

the Mississippi drainage-basin, and finds its outlet through Hudson's bay to the Arctic ocean. The eastern or Appalachian sea had its outlet about Chesapeake bay, and was long and narrow.

In the larger or western ocean the fauna was modified from time to time by the reverse, or Arctic, currents that came and went as the land-levels and contours became modified. This condition continued until the close of the Carboniferous age, the northern portion, gradually rising, constricted the northeastern outlet, and established lagoons which finally became brackish, as is shown by the fauna they contained.

Third Stage.—The southern part was still under water and Upper Silurian conditions continued, affording a home for the Niagara and Clinton forms of life long after Devonian conditions had been reached in the northeast region. This result is shown by the enormous thickness of the Upper Silurian deposit as compared with the thin black shale which carries *lingula subspatulata* as a characteristic Devonian form. The shales are old mud-banks, and the ocean-bed, now forming Georgia, Alabama and Tennessee, was too far distant from shore to be within the area of the main deposition of mud from the lands of the northeast. The rain must have been excessive, since the moisture-laden air of the Gulf Stream met the frozen winds from the Arctic; and as a result of this heavy rainfall the mud was formed. These conditions continued until Tertiary times.

The Tertiary Period.

Astronomers tell us that many million years ago the precession of the equinoxes caused the earth to be so many million miles further from the sun in its annual course, that at the time of its greatest distance in a period of 10,500 years, the winter was 25 days longer and the summer 25 days shorter than at present. This condition caused the growth of the polar ice-caps, and the earth, following the laws of symmetry which affect all revolving spheroids, suffered surface-changes of level. This condition continued, as shown by the evidence, until the close of the Tertiary period. Nothing was done in a hurry; a gradual local upheaval occurred, during which time the drainages became established through certain channels. A second terrestrial disturbance caused the old axis of upheaval to be-

come dormant, which resulted in a second local upheaval. These successive elevations have been obscured beyond local identification by later denudations and seismic changes.

The Laurentian highlands were a part of the first important result; and later there was a cross-country or E–W. elevation of axis that extended from the Blue Ridge westward in an irregular curve through Virginia into Ohio.

The pre-glacial drainage of the northern area has been the subject of several important monographs, and cannot be discussed here. The point of interest is that the drainage, thus established, cut rapidly down to the base-level and proceeded to erode backward to the drainage-heads, and to broaden the valleys at the lower ends. The "cols" left are marked by low slope-angles. Everything attests the slow and gradual development of the drainages. Since this is the key to the situation of Appalachian development south of the Ohio-North Carolina divide, it is important to note it. Another point suggested is, that, after local terrestrial action ceased, it was not resumed at that particular point. In other words, when one fault originates another one near usually becomes dormant.

The Ohio-North Carolina uprise had the very important result of so diverting the Gulf Stream that Hudson's bay was no longer the recipient of the current of warm water that had artificially maintained it in temperate climate. This was succeeded by normal cold water, and the channels were rapidly closed by ice. The main body of warm water was split, one part going out by Virginia, Delaware and New Jersey to the north of the uprise, while the southern half, skirting the Blue Ridge about Casars Head, S. C., established an Atlantic flow to the eastward.

Refrigeration continued. The earth's bulk is diminished by cold and increased by heat. It would be easy to calculate an imaginary shrinkage by the loss of a certain quantity of heat-units for a term of several thousand years; but this would not be profitable, since there are no means of proving any part of the calculation. Suffice it to say, that no elevations of surface or crumpling of strata come anywhere near the result indicated by the calculation. There our Appalachian fold originated.

Why the Fold?

All bodies under compression laterally and having one free side, yield towards the free side. In the present case this free side was the bottom of the Appalachian sea. There was less to lift; consequently when the weight of pressure exceeded the weight of the mass of earth the bottom began to rise. The plexus of Balsam mountains in North Carolina was the first resultant—a symmetric group which has suffered longer erosion by drainage than any other. From the base westward a plain of Carboniferous period was slowly rising, as far west as Duck river, Tenn., or even further. Beyond it was the arm of the Gulf Stream still flowing northward.

We now come to a law which may be provisionally adopted, since it explains the geological plications of east Tennessee as nothing else will.

Considering the mass of the Blue Ridge as exerting the pushing force, and the Rocky mountains as the other jaw of the vise, we find that the action near the pushing force is more intense than further away. This explains why the Smoky mountains and the Balsams are literally piled on end, and why the enormous heat generated by the lifting of such masses caused hot springs in all directions, the action of which is shown by the degradation of the pegmatites to secondary minerals in North Carolina; also the general metamorphosed condition of the Smoky Mountain shales, quartzites and limestones, which may throw light on the genesis of the marble and zinc of east Tennessee. With the time-element added, it also explains how the valleys of Virginia and east Tennessee came into being. Drainages westward had to go somewhere, and the folding, incident to positions next to the high fold, caused low folds. Under this law, the high fold had to be east of the low fold; and the erosion of centuries completed the sculpture. Where there is an anticlinal fault, the east side has out-travelled the west side. Under this law the priority of growth of the main anticlinals of the system can be traced. The eastern ones were the first, and they completed their movement before a new one started. That is why the drainage-streams of the Blue Ridge were not turned or diverted. They were lengthened from their heads downward. The elevation of the land was steady but slow, and in no case, on a large scale, was it jerky. The

uprise of the land was equaled by the wear of the beds of the streams.

The same law will explain why the crowded anticlinals of east Tennessee give place to the wide gap of moderate curvature that carries on it Dirtseller, Pigeon, Walden's ridge and other western outliers of the crowded anticlinal areas. After that, pressure is shown by more or less curvature of the bedding of the stratification.

Before leaving this subject, it may be added that, after the earth had passed through this cycle of cold and had commenced to become warm, a stretching of surface took place, as is shown by the evidence. Possibly the floor of the Pacific ocean was lowered gradually about that time and from that cause,—a view which might be supported by some evidence.

For the sake of clearness it may be said that the gradual uprising of the land diverted more and more of the Gulf Stream eastward. The contrary currents, as the ice receded, ran south, reversing the old Paleozoic course and dropping the glacial drifts on the stratified rocks to the southward. These orogenic movements continued until north Georgia and Alabama with east and middle Tennessee had been lifted to the height of the general Carboniferous peneplain, with the highest tilt on the said peneplain on the east side, under the law above stated. Of course, the valley structures were eroding as fast as the level was being raised, but that does not invalidate the law.

It is outside the limits of the present paper to go into the growth of Tertiary and subsequent formations in the Gulf and Mississippi embayment.

With these brief enunciations of geological conditions, I proceed to the particular study of one mountain-mass and the geological and economic results occasioned by the successive changes of its growth.

IV. Lookout Mountain.

Lookout mountain, of which an excellent view from Chattanooga is given in Fig. 1, is unequally divided between Georgia and Alabama, with its narrow and elevated northern termination running a few miles into Tennessee. Geologically, it is part of Sand mountain, Ala., from which it is separated by a couple of anticlinal valleys. It is essentially a synclinal mountain, though

it has, in its northern half, two minor anticlinal axes that have had a marked influence on its topography. Let us view it at the time when, by the operation of the above-named causes, it had got perhaps one-third of its present height. Shinbone valley was buried in the talus of the mountain, and McLemore's, Wills and Lookout valleys did not yet exist. The general scheme was a plain with a slightly upturned edge at the east side tilted by the Shinbone uplift, still slowly going on and not far advanced. The change had been so gradual that the ordinary drainage-conditions had not been disturbed. There was a large surface to drain, and the deep gorges, extending to the sandstone, resulted. In many cases these gorges, the "gaps" of the country people, are now used for roads. The mountain kept rising. Then the Shinbone anticlinal became dormant and the McLemore's uprise started. Here was a dam, gradually rising; the water found its way northward and eroded McLemore's cove, and southward, the long cañon of Little river.

Little river would have had the same chance of valley-sculpture if it had not been that a large proportion of its drainage was cut off by the next uplift-axis, that of Wills valley, the northern point of which ran under the mountain at Rising Fawn and turned the drainage northward, where it scooped-out the cañon-like gorge of Lula falls. It did more than that. It cracked the weaker lower strata and stretched them till drainage formed a series of pot-holes; two or more were in the course of the old river that ran through Sugar Camp hollow to Flintstone. The handsome cataract of that day wore back till the first pot-hole broke through, and a natural bridge was the result. The abutment is still standing on the south side, and is part of the trail leading from Flintstone. Finally, the bridge fell in and formed a dam. The first overflow channel is still visible at the south of the abutment. The dam broke, and the water, circling for an outlet, washed away Shinbone ridge locally, and left the dam, of water-worn Lower Conglomerate sandstone, piled up on the south of the Gap almost like a terminal moraine of a glacier. The present Lula lake is the last of that series of pot-holes and the present drainage-area is insignificant.

The small anticlinal Lookout valley is where the south end of an anticlinal ran into Deerhead cove.

Some accidental and local causes of drainage caused the two valleys to be joined by the gap at Rising Fawn. From the steep side of the western aspect of Lookout mountain, local newness of valley-sculpture, consequent upon a deepening of the valley-floor, is indicated.

The Iron-Ore.

The above statement is only a recital of the dynamic conditions which led to the formation of the red fossil-ore. Whenever the stresses of a bridge or truss are calculated, one portion of the structure has a compressive and crushing strain and another a tensile strain. The same condition applied to Lookout mountain when it was bent into a synclinal trough; the upper part was subjected to a crushing and the lower to a tensile stress. The members under compression are massive sandstone; while the members under tension were and are sandy and calcareous shales, limestones and thin-bedded rocks generally. As a result, the Coal Measures at *A* (Fig. 2) were gradually oxidized, and the pyrites became a sulphate of iron solution, which filtered through the sandstones to the axis of the mountain, where, in course of time, it formed a more or less concentrated solution of iron sulphate, and the bowl, *X*, *Y*, *Z*, was constantly fed by the enriched solution. The mountain being axially fractured at its central base as the result of the tensile stress.

The floors of the valleys were too high for bottom-drainage from this acid earth-reservoir. It dissolved the lime from the calcareous shales of the Clinton period. By simple gravity it had already passed through the axial fissures of the mountain limestone and the black shale; the first limestones that were included in the terrestrial reservoir, however, were acted on chemically, and the water became charged with calcium sulphate, and was siphoned upward to the accidental level of the springs. Mr. Hayes makes the objection that he has never seen the original limestone unaltered. I have so seen it, but only in one instance. It is indeed rare, and it would be a wonder if it were not. In proportion as the drainage-outlets (springs) of that early day assumed lower levels, due to the deepening of the valley-floors, the limestone outcrops of the higher points escaped impregnation, and, being left high and

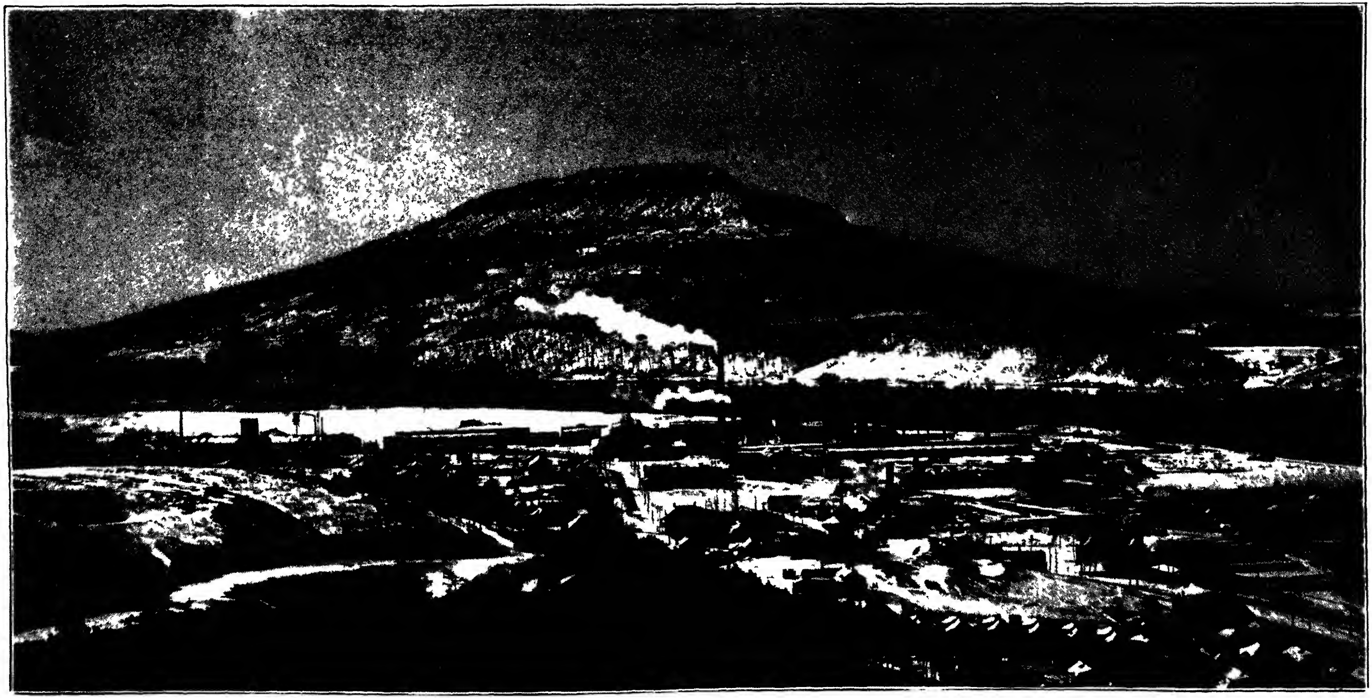

Fig. 1.—Lookout Mountain Viewed from Chattanooga, Tenn.

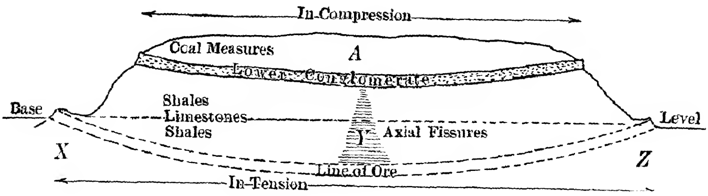

FIG. 2.—SKETCH OF SECTION OF LOOKOUT MOUNTAIN, ILLUSTRATING BOTH COMPRESSION AND TENSION STRESSES.

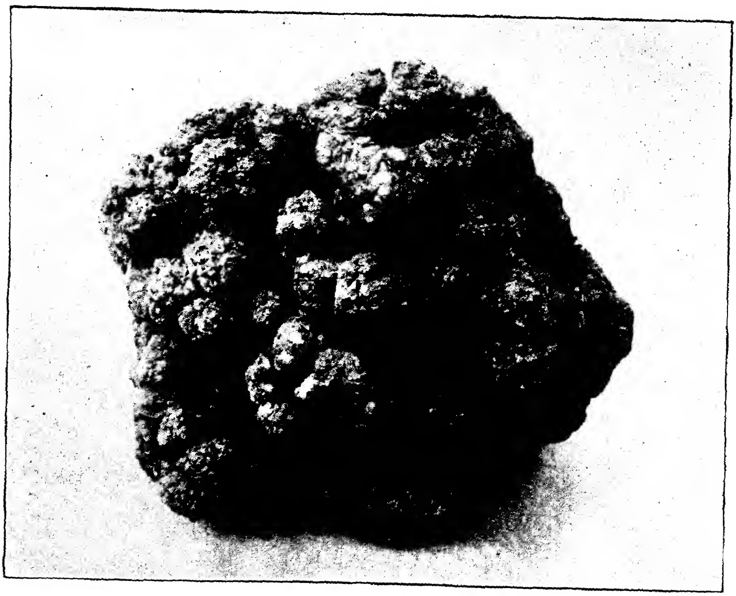

FIG. 3.—"CAULIFLOWER" IRON-ORE.

dry, they were subject to all the causes affecting surface-limestones.

In conclusion, a singular instance of this impregnation *in situ* is afforded by an unusually high limestone which occurs a hundred feet or so below the Lower Conglomerate. On the road from Valley Head to Mentone, I saw about 2 ft. of a fossil limestone, the upper part of which had been converted into a regular iron-ore. It had a water-tight shale below it, repeating on a small scale the action of the larger influence of the Tertiary and Mesozoic agencies. Furthermore, it contained pieces of coal about the size of wheat, and occasionally the size of a coffee-bean. With regard to the character of this coal, it had the clean cubic and conchoidal fractures of coal, and was neither sea-wood nor wood; undoubtedly the pieces were deposited in the ocean, but I do not know from whence they came; probably the ice brought them from some other region, since this time was before the lowest coal of the district came in. As an additional puzzle, I may say that at Inman, Tenn., was found a lenticular mass of coal, 10 or 12 ft. long, 2 ft. wide, and several inches thick, embedded in the Clinton ore. I have specimens showing the ore and coal together. Probably the ice must have been responsible for this effect. Favoring conditions, rather than the date of genesis, have determined the growth of such formations.

Mechanical Texture of the Ore.—If my views are correct, it follows that every particle of the iron has been deposited from solution. If that be granted, then the laws of segregation of like substances from solution must have been followed.

A bunch of "cauliflower" iron-ore, having the peculiar "cauliflower" structure, is shown in Fig. 3. This specimen was originally a lime stalactite, but recomposition *in situ* has substituted iron for lime.

There was another complex action at work. The enormous quantity of carbon that was to be locked up in the coal-beds of the coming Carboniferous age was largely in the form of free carbonic acid, which conferred upon the rain an intense solvent power for the Silurian limestones and the harder and older rocks that were above drainage-level. This condition made the sea-water rich in lime, which is shown in the enormous profusion of corals, brachiopods and mollusks. When these shells

were no longer tenanted, they were thrown by sea-action on the beach; superficial solution eroded their surfaces, eolian sand-action ground them, waves fractured them till those that escaped actual trituration and re-solution were washed into the deeper water, the resultant carbonated water-action being corrected by the plant-life which, in turn, acted on the dissolved gas. Infinitesimally small differences in permeability caused local *nuclei* of iron-deposition in the texture of the rock, which occurred after the shell-mass had been converted by time and pressure into rock. The following evidence proves the existence of such local pressure. I have a specimen of *platyostoma* that originally rested on its side but now has its two sides pressed almost together. The breadth of the hinge-line has become the thickness of the shell.

While infiltration of waters charged with iron sulphate was slowly converting the iron into ore, the action of carbonic acid gas in the same rains, together with the humic and ulmic acids derived from surface vegetation, had rendered soluble a portion of silica which was concurrently introduced and became a constituent of the ore, being, I suspect, the source of the silica which Diller, in the passage above quoted, describes as "radially fibrous and optically negative, like chalcedony."

A confirmation of this conclusion was observed at Battelle, Ala. The ore there occurs in the Lookout valley on the west, a black shale ridge supposed to be Devonian, having the siliceous bottom of the Carboniferous on its eastern haunch. The ore dips to the east, being the western margin of a synclinal trough. The Alabama Great Southern railway runs to the east of this ridge. The hard ore of the deposit contains, on an average, about 28 per cent. of iron and 9 per cent. of silica. To ascertain whether the ore-deposit was of any extent or could be reached by shaft, a drill-hole was sunk in the East Valley Carboniferous deposit fully half a mile east of the outcrop, which showed a 4-ft. deposit of ore at 800-ft. depth, having the following composition: Fe_2O_3, 73.23; CaO, 14.33; SiO_2, 4.52; and P_2O_5, 0.35 per cent.

No surface influence could have made any impression at this depth, which exceeded 750 ft. below the drainage-base level. It was alike free from lime-leaching and siliceous infiltration. This fact is a broad indication that the deposit was formed

under such conditions as exists in this particular field, and it would seem to indicate the probable impregnation from axial influences. Mr. S. W. McCalley, in several conversations on this subject, was inclined to take the view that the original iron-ore was deposited as such, saying that he has seen a syncline in which the deep drilling passed through strata of the proper horizon where ore showed at the edges, and found no ore in the drill-hole. This effect might indicate that the bottom of the fold lay too deep to be affected by the basin of enriched water, whose downward limit is, as has been said, soon confined by the mud resulting from the insoluble material in the limestones that are dissolved,—the mud washing off the exposed faces as each particle became loose. Much of the granular appearance of the ore may be iron which coats the small partly-solution-rounded shell or coral particles in its characteristic pisiform mode of segregation. When a broken shell is partly dissolved, the tendency would be toward flattened or elongated grains, since solution in *brachiopod* remains would be greater on the grain than across it. With *protozoa*, the organic structure may be more or less obvious or wholly obscured according to the degeneration of structure consequent on mineralogical replacement.[4]

V. Conclusions.

These material features and facts concerning Lookout mountain might be dismissed as local, were there not certain underlying facts that are keys to the conditions attending the conversion of limestone into ore. These facts are:

1. The presence of synclinal plateaus, now often reduced to peneplains, the troughing having been caused by crushing.

2. Streams that have cut their way to the base-level, effecting a lodgment and establishing a bed on the Trenton limestones.

3. Mountain slopes of softer materials and easy of wear, that were capped by heavy sandstones. These slopes, undermined, broke off, and formed a more or less protecting coating to the talus of the mountains.

4. The continual overflow from the underground basin, de-

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[4] Since writing the above, Mr. McCalley has kindly shown me his microscopic sections of the ore. In every case either the center was lime, or animal structure was evident.

scribed above, formed innumerable springs, which, by their discharge, modified the valley-sculpture.

5. The conditions of orogenic activity were transferred from the eastern American Continent to other parts of the world.

6. At the outcrops, familiar influences have removed a part of the lime still remaining in the ore, and have introduced silica, etc.

7. The process is still active. Occasionally a little of the ferrous water escapes unchanged; we call it a "sulphur" spring. Where the normal conditions exist, the water that fell as rain has been rendered hard by calcium sulphate, the iron from the tops of the mountains replacing the lime *in situ*.

I have never met a case at variance with the principles announced above, any conflict being easily traceable to local causes.

One other consideration is involved. When the axial channels were made by stretching the base of the anticlinal mountains, the influence would be deep; but at the first action of substitution of iron for lime, the clays and other materials of the limestones, together with the dirt, would be deposited and choke up the channels below a level lower than that of the existing drainage, thereby protecting the deeper strata from impregnation, and localizing the area to the one porous coquina-like limestone.

The whole subject needs study, and I ask the co-operation of those, who, by location and occupation, have daily access to the ore, in noting such facts as would seem to bear on the subject either for or against the views I offer. Then, with broader light, we may make substantial progress.

The Electrolytic Assay of Lead and Copper.

BY GEORGE A. GUESS, SILVERTON, COLO

(British Columbia Meeting, July, 1905.)

THE increasing demand for greater speed and more accuracy, in making daily assays of ores and products from mills treating material containing but very small quantities of lead and copper, has caused the older analytical methods to be supplanted by new ones devised to meet the needs of modern work.

For "control" work in copper-analyses, I had, previous to the present equipment, introduced in my laboratory the ordinary electrolytic method, using hollow cylindrical electrodes; and with these I began a series of experiments in determining the lead-content of daily mill-samples and controls. The results, proving accurate and satisfactory, I then devised, with Mr. H. E. T. Haultain, a cheaper electrode than the ordinary jacket-electrode, which costs from $15 to $20,—the expense of the older form making the installation of many units very costly.

The form of cathode finally adopted as the most satisfactory, shown in Fig. 1, is cut from 0.001-in. platinum foil. It is 12.5 cm. long, and is divided into a blade 4 cm. wide and 6.25 cm. long, and a tongue 0.7 cm. wide and 6.25 long, the immersion area being 50 sq. cm. and weight 1.5 grams. The blade is first sand-blasted and then corrugated lengthwise, in order to impart the necessary rigidity. Strips of platinum foil 0.001 in. thick, 12.5 cm. long and 0.5 cm. wide, having a median corrugation, form the anodes. Three electrodes are used in each cell; one anode in the middle and one cathode on each side of the anode. These electrodes are connected to slotted aluminum terminals, in which they are held by contact pressure. The terminals are $\frac{5}{16}$-in. rods, projecting 2 in. horizontally in front of the wall of the cabinet; at the back the middle electrode (anode) is connected with one pole of the current, and the two outer ones (cathodes) with the other pole.

The present equipment in the laboratory consists of two cabinets of 30 cells each, one used for lead, and the other for copper-determinations. Each cabinet is individually wired in series, but both are connected in multiple and receive a current of 130 volts, which is controlled by enameled field-rheostats, one for each cabinet. (See Fig. 2.) Formerly, lamps were used to furnish the resistance. One voltmeter and one ammeter reading to 0.02 amperes is sufficient for both cabinets.

Exclusive of wiring at and from the power-house, the cost of installation, made by Mr. Haultain and myself, was much less than $200. The platinum, ordered in sheets, was cut, sand-blasted and corrugated. The aluminum was purchased in ingots and cast into terminals. A carpenter took three days to make the cabinets. With this equipment I make an average of 45 lead- and 50 copper-determinations daily, besides attending to other work of the office.

I am not aware that any other electrolytic method is in practical daily use for the estimation of lead. In devising my method I have referred to the published articles of various chemists, and to the books of Classen, Neumann and Smith bearing on the subject. Briefly, the method is as follows:

The ore, weighed into a tall battery-beaker of 100-cc. capacity, is digested with 10 cc. of nitric acid. The lead sulphate formed is readily dissolved after boiling by the addition to the beaker of from 10 to 20 cc. of a saturated solution of ammonium nitrate containing 20 per cent. of free ammonia. After solution the beaker is nearly filled with water, and from 10 to 20 cc. of nitric acid added. The solution is now ready for electrolysis. A wide range of current-strength is permissible, but from 1.5 to 2 amperes is most satisfactory; this amount keeps the solution sufficiently hot during the electrolysis. At the end of two hours, the lead is completely deposited in the form of peroxide on the anode. The anode is then removed, washed in water and in alcohol, ignited and weighed. The theoretical factor is 0.866; but in practice 0.855 is found to be more accurate; probably due, as Hollard says, to an excess of oxygen in the peroxide.

The accuracy of this method ranks with that of carefully-made electrolytic coppers, and its great advantage is the small amount of the chemist's time required. In the presence of

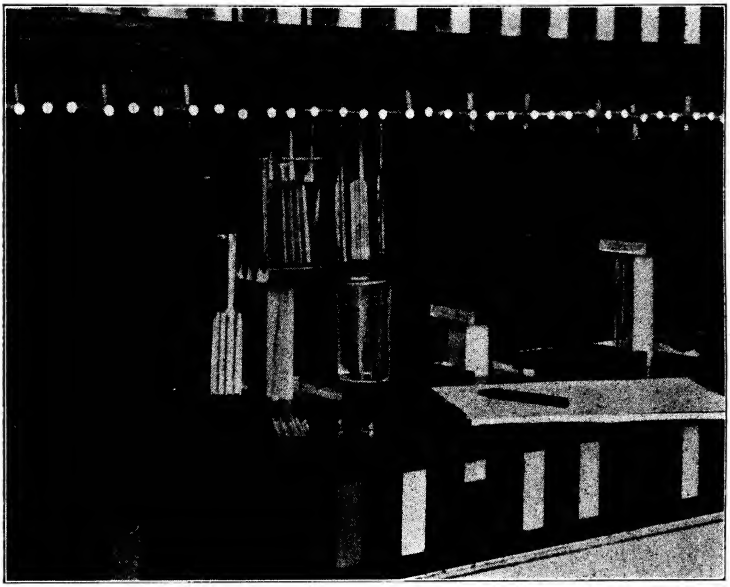

FIG. 1.—ANODES, CATHODES AND TERMINAL CONNECTIONS.

FIG. 2.—ELECTROLYTIC CABINET SHOWING RHEOSTATS, VOLTMETER AND AMMETER.

manganese or antimony, it is necessary to have a large excess of free nitric acid in the electrolyte, under which condition neither element interferes. Bismuth, even in the presence of very large amounts of free nitric acid, is partly precipitated as bismuth oxide with the lead. Its presence can be recognized by a light-blue color given to the peroxide coat. Arsenic and tellurium have to be removed before electrolysis, for, if present in large amounts, they effectually prevent any deposition of lead. Unless the anode is sand-blasted, only a comparatively small amount of peroxide will adhere, but, properly sand-blasted, adherent deposits of 250 mg., and even up to 600 mg., of peroxide may be obtained in daily work.

For weighing the pulp I use a weight of 855 mg., which has been christened a "plum," and multiples thereof, in order to avoid the necessity of calculating each result, the weight of peroxide found being called lead.

The same style of electrodes are eminently suited for copper work. Apart from the cost of platinum the great drawback in the use of the electrolytic method for copper-determination in daily work is the time required for the electrolysis, usually amounting to from 8 to 12 hours. Many substances were tried in the attempt to lessen the time of the copper-assay, but the cathode was usually dark colored when the current density was increased. While determining the copper in a concentrate obtained by Mr. Haultain with the use of No. 4 hard oil of the Standard Oil Co. and retaining some of the grease, a peculiar glossy luster was noticed on the deposited copper. Some of this hard oil was treated with nitric acid, and the solution, freed from grease, was then added to the solution to be electrolyzed. The current was increased to 5 amperes, which is about 25 times the usual practice, and still the copper continued to come down bright. The preparation of this "nitro" compound, called "dope," for use in electrolytic copper-determinations, is as follows:—hard oil is boiled with strong nitric acid, cooled, and the grease removed, which leaves a deep-red solution that, when added to a nitric-acid solution of copper, will permit the use of high current densities and yet, under these conditions, deposit all the copper pure and bright in 3 hr. Moreover, arsenic and antimony, which interfere seriously in ordinary electrolytic precipitation of copper, do not contaminate

the deposit of copper, even if present in very large amounts. More than 3,000 copper-determinations have been made in this way, and experiments have also been made on smelter flue-dust and copper-dummies containing large amounts of arsenic and antimony. In these cases the results were always satisfactory.

The use of the oil in electrolytic work is as follows: the ore, weighed into tall battery-beakers of 100-cc. capacity, is digested with 7 cc. of nitric acid, and boiled until nitrous fumes have been expelled. About 2 cc. of dope, diluted with nitric acid, are added (or it may be added with the acid), the beaker, filled with water and allowed to settle for a moment, is then electrolyzed with a current of 1.5 amperes for 3 hr. The cathode must be sand-blasted, otherwise the copper is apt to fly off when it is ignited.

There should be no gassing whatever at the cathode during electrolysis. The cathodes frequently gas when the current is first turned on, but if turned off for a second, and then on, the gassing should cease. The cathode frequently gasses at the end of 3 hr , when the assay is finished.

Several different nitro-hydrocarbons have been tried instead of the dope in the 3-hr. copper-assay, and of these, di-nitro-alpha napthalene produces, with a little more care during electrolysis, results nearly equal to the dope.

Anthracite-Washeries.

BY GEORGE W. HARRIS, NEW YORK, N. Y.

(British Columbia Meeting, July, 1905)

Introductory Summary.

In the earlier period of anthracite-mining, much coal was wasted, both underground and in the culm-banks on the surface. Such waste is common in the development of new mining-districts, in which, as a rule, only the richest material can be profitably treated. In the anthracite-region, special causes operated to increase this evil. The mines were generally worked under 20-year leases, and royalties were paid upon such coal only as was actually marketed. The lessees consequently cared for immediate profit solely. They were not bound to win all the coal they exposed, or to leave it in such condition that their successors could win it. Nor was it their interest or duty to educate consumers in the use of their product. The market called for coal of large sizes; and such coal they furnished, throwing away the rest. Any pains taken by them to bring about a more rational use of coal by their consumers would have borne fruit, after their leases had expired, to the benefit of somebody else.

A full statement of the situation was given in 1893, in the report of the State Commission, appointed in 1889 to investigate the subject.[1] That body included the names of Heber S. Thompson, William Griffith and the late Eckley B. Coxe.[2] Its report gives special attention to the utilization of the old culm-banks.

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[1] Report of Commission Appointed to Investigate the Waste of Coal-Mining, with the View to the Utilizing of the Waste (May, 1893).

[2] For a statement of Mr. Coxe's great services in this respect, see Dr Raymond's Biographical Notice of him, *Trans*, xxv., 458; also, for further information, *Trans.*, i., 9, 55, 59, 406; iii., 13; v., 417, 465; ix., 294; xi., 7; and sundry volumes of the Pennsylvania Geological Survey, especially A_2 (1881), on "The Causes, Kinds and Amount of Waste in Mining Anthracite."

Meanwhile, this colossal waste, both below and above the surface, of a valuable and limited national treasure, had received its first check through the concentration of the control of the anthracite-mines in the hands of a few wealthy firms and corporations, which had both the motive and the means for measures of economy looking to a more distant future, and were guided by intelligent men, who knew the value of scientific advice.

The consequent improvement of mining-methods, by which the unnecessary waste of coal underground was stopped, is outside the limits of this paper, which is concerned with the waste in the breaker, represented by the old culm-banks.[3] The first step towards the diminution of this waste was the commercial introduction of smaller sizes of coal. This required the education of consumers to the use of such sizes. "Pea," "Buckwheat," "Buckwheat, No. 2" ("Rice") and "Buckwheat, No. 3" ("Barley") successively achieved recognition as articles of trade. The rapid increase in the production of the sizes below chestnut is shown in Table I., taken from a report by H. H. Stoek,[4] for the years prior to 1903.

TABLE I.—*The Product of Small Sizes of Anthracite from* 1875 *to* 1903.

Sizes	1875	1880	1885	1890	1895	1900	1903.
All sizes	20,000,000	23,500,000	32,000,000	37,000,000	46,500,000	51,500,000	59,362,831
Lump, steamer, and broken	7,500,000	9,000,000	7,500,000	9,000,000	8,000,000	7,500,000	7,179,720
Egg & chestnut	11,000,000	11,500,000	18,500,000	19,000,000	24,500,000	26,000,000	(*a*)31,112,120
Chestnut and larger	18,500,000	21,000,000	26,500,000	28,500,000	32,500,000	33,000 000	
Pea .	1,000,000	2,000,000	3,500,000	4,500,000	6,500,000	7,500,000	8,576,340
Pea and smaller	2,000,000	3,000,000	6,000,000	8,500,000	14,000,000	18,000,000	..
Buckwheat and smaller	150,000	500,000	2,000,000	3,500,000	8,000,000	11,000,000	(*b*)12,494,651

(*a*) Including stove-size. (*b*) Buckwheat Nos 1, 2 and 3.

[3] I speak of the *old* culm-banks, because the recent accumulations of that class, though they look to the inexperienced eye as carboniferous and promising as their predecessors, are by no means equally valuable. Many of them represent essentially only black slate, not yet (and perhaps never) to be utilized for its very small content of combustible carbon. One of the largest old banks is at the Von Storch colliery of the Delaware and Hudson Co., within the limits of the city of Scranton.

[4] "The Pennsylvania Anthracite Coal-Field," 22*d Annual Report, U. S. Geological Survey,* Part III., p. 92 (1902).

The reports of the collieries of the Girard Estate show that small sizes of coal were thrown upon the dump, prior to 1866, at which time chestnut was the smallest size sent to the market. In 1867, pea-coal was utilized for fuel; in 1878, "buckwheat" was shipped; in 1895, "rice;" and quite recently "buckwheat No. 3" ("barley"). No record of shipments of culm or coal-dust from the Girard Estate collieries was made prior to 1902.

A fair estimate of the quantity of coal and coal-dirt sent to the culm-banks, from the commencement of mining-operations up to 1903, is about 315,700,000 tons, or 35 per cent. of the total production during that period.

The different conditions of mining in the anthracite-regions have affected largely the character of the resultant culm-banks. In the middle and upper portions of the Lackawanna region, from near Wilkes-Barre to Forest City, the seams have little pitch, and most of the loose rock resulting from mining-operations was left in the chambers; while in the steeper seams of the middle and southern regions, practically the entire product of the mine was frequently loaded in cars and sent to the surface, the rock and much of the coal-screenings being placed in the same dump. Moreover, the dry preparation of coal in the Lackawanna region tended to a greater saving of the smaller sizes, which were stocked in banks. On the other hand, wet preparation in other regions was more wasteful of the fine sizes, much of the mined coal being carried away and lost in the water used in washing. In other instances, the culm was spread over many acres of ground, destroying vegetation and generally contributing to the barrenness of tracts already denuded of timber. Under these conditions the recovery of the smaller sizes of coal became difficult, if not commercially impracticable. These circumstances indicate the Lackawanna region as the natural field for washery-operations; and it is in the Lackawanna and Wyoming valleys that the greatest development of this branch of the coal-industry is found.

During the year 1903, the shipments of coal from washeries[5] amounted to 3,677,909 tons, of which quantity, 2,875,981 tons (about 78 per cent.) came from the Lackawanna region, and

[5] *Report of the Department of Mines of Pennsylvania*, Part I. (1903).

309,244 tons from the Pottsville districts. This output from the washeries constituted 5.92 per cent. of the total quantity of coal sent to market in 1903.

Typical Modern Plants.

General Description.

In view of the above statistics, a description of one or two typical modern plants is appropriate.

In general, the machinery and some of the methods used in washeries do not differ materially from those seen in portions of breakers preparing the smaller sizes of freshly-mined coal; in fact, the washery is often an annex to an old breaker in which the coal is prepared dry. The important difference is that the washery is essentially "wet:" the success of this practice being largely due to the abundant use of water, which not only removes clay and coal-dirt, but greatly assists in the separation of the various sizes on the screens. It may be said that the washery, while it has features peculiar to itself, is but a development of the breaker to meet special requirements.

Starting at the culm-bank, the first step in the operation is the transportation of the material to the washery. The culm is fed to conveyors by hand or by steam-shovel; then loaded into cars, which are hoisted to the top of the washery; or, as is becoming common practice, it is flushed into conveyors by means of a hose, as in hydraulic mining—a stream of 2.5-in. diameter being sufficient to carry the culm to the conveyors in sheet-steel chutes placed at a slight angle to the horizontal (see Fig. 1). As the bank recedes, the chutes are taken up, the underlying culm is shoveled into the conveyor, and the scraper-line is moved closer to the bank. Generally, there are several lines of conveyors, the one nearest the washery being permanent, and the others (feeding into it) movable. A difficulty often encountered in working these banks is the occurrence of ashes from the boilers of former times, which have been mixed with the coal on the bank. The separation of these ashes from the valuable portion of the dump is often an expensive operation.

This general practice of flushing into conveyors is followed at the Capouse washery of the Scranton Coal Co. in the Keyser

valley, north of Scranton, on the New York, Ontario and Western railroad. This company also operates the Mount Pleasant washery at Scranton, and the Raymond washery at Archibald.

The Capouse Washery.

At this plant there is a fixed scraper-line, 380 ft. long, and a 500-ft. movable conveyor, each driven by an independent 10- by 16-in. Nagle engine. These endless-chain conveyors run in a framework, the bottom line moving in a sheet-steel or cast-iron trough and returning on T-rails overhead.

The conveyor delivers the fine material at the foot of the main elevator of the washery, where it is washed, sized, the slate removed and the large pieces of coal re-broken. A typical plant for handling culm containing few pieces of large size is illustrated in Fig. 2. These conditions are similar to those at the Bellevue washery, which I have elsewhere described.[4]

The washery, having a capacity of 120 tons of prepared coal per hour, occupies an area of about 53 by 65 ft. at the foundations, and is approximately 80 ft. high. Figs. 3, 4 and 5 show the details. The frame of the building is of mortised construction with 12 by 12-in. posts braced by 8 by 8-in. timber. The stringers supporting the machinery, and those under the coal-pockets are of 12 by 14-in. oak. The compactness of this plant is quite striking when compared with coal-breakers having a similar capacity. In marked contrast also is the absence of the clouds of coal-dust which arise during working-hours at the breakers in the Lackawanna region.

The preparation of the coal at the Capouse washery begins at a point where the scraper-line discharges into a chute leading to the main elevator. A man stationed here throws out large lumps, breaks those containing coal into smaller pieces, which are then thrown into the elevator-boot, *A* (see Fig. 5), removes any pieces of foreign material—wood, iron, slate, etc., and controls the feed of the coal to the elevator. In the washery, the main elevator is 65 ft. long from center to center of sprocket-wheels, and carries 71 water-tight buckets, each 12 by 28 in. in size. The elevator material is discharged into a chute, *B*, which feeds the first shaking-screen, *C*. (In washeries

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[4] *Mines and Minerals*, Scranton, Pa., June, 1903, p. 481.

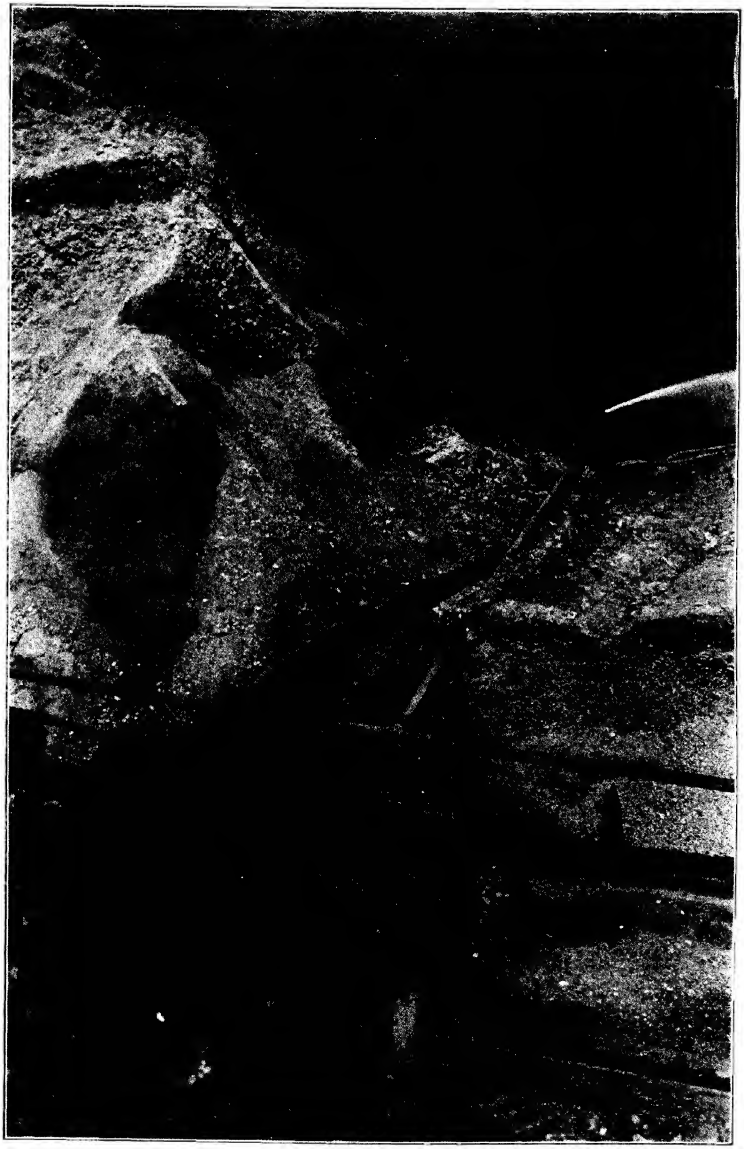

Fig. 1.—Flushing Culm into the Troughs which Feed the Conveyors.

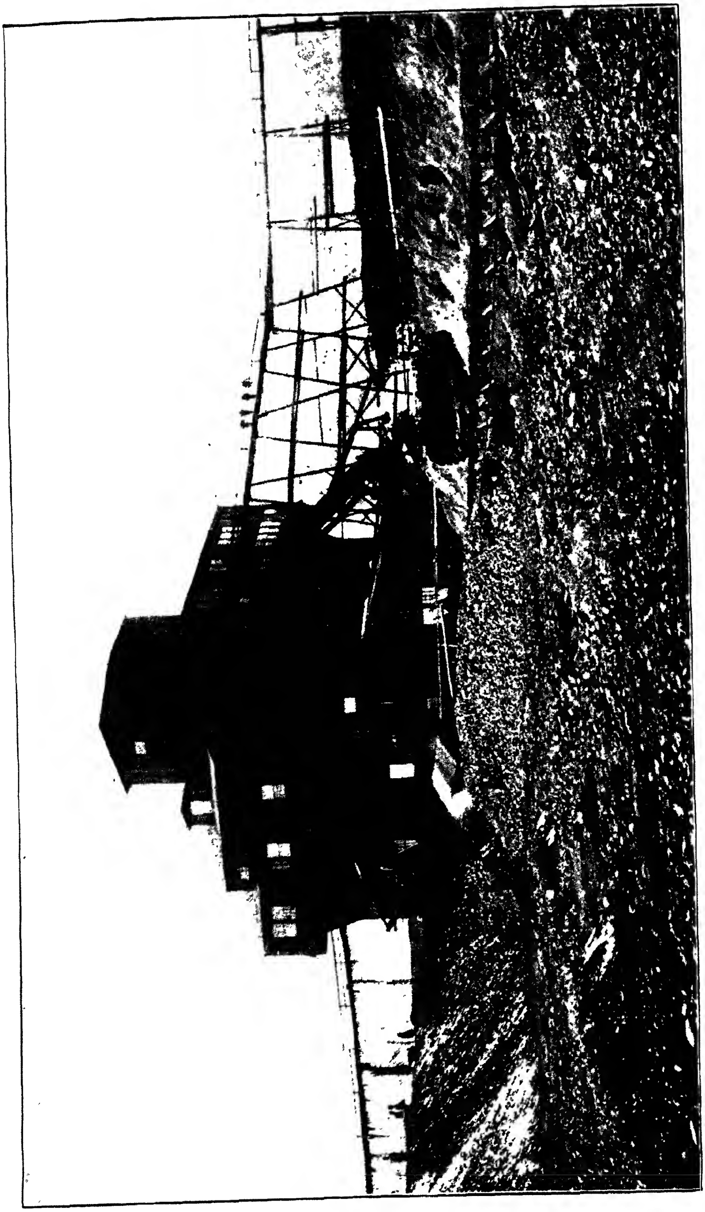

Fig. 2.—Capouse Washery near Scranton, Pa.

the revolving, circular screen has been almost entirely superseded by those of the flat, shaking type, because the fine mesh

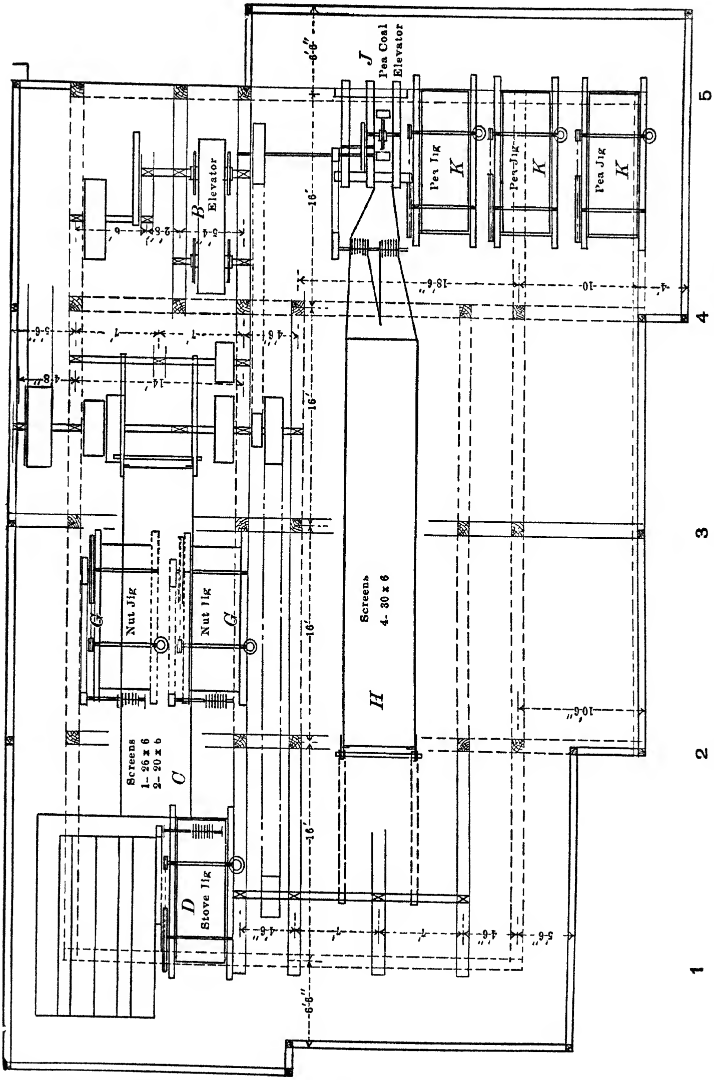

FIG. 3.—CAPOUSE WASHERY—PLAN, SHOWING THE POSITION OF THE MACHINERY.

of the former becomes clogged with dirt, despite all efforts to prevent it.)

The shaker or "mud" screen, *C*, consists of three screens, the top one being 27 by 6 ft., and the two others, 20 by 6 ft. in

area. The screens are driven by eccentrics, set so that each one receives a thrust at a different time from the others, an arrangement which is necessary in order to avoid undue vibration of the framing. As soon as the material strikes the top screen, it is sprayed with water from a perforated pipe; and, passing down the screen, goes under a box from which a copious stream of water overflows. For the first 21 ft., the top screen has

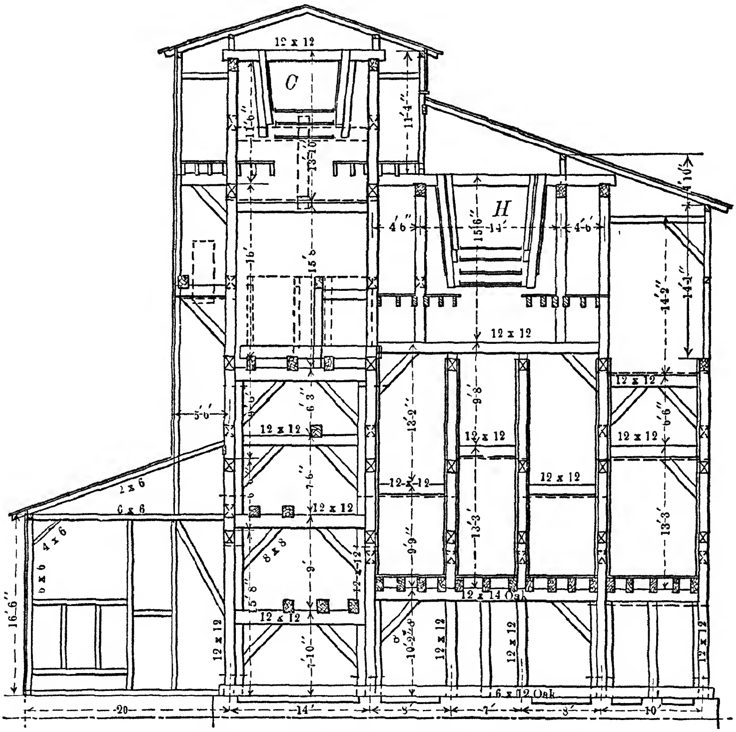

FIG. 4.—CAPOUSE WASHERY; TRANSVERSE SECTION.

1.5-in. round holes, through which the chestnut and smaller sizes pass to the screen below. Following the 1.5-in. round holes are angle-irons, having the angle uppermost (Λ); the lower edges being 0.75 in. apart, which allows flat pieces of slate to fall through. The last 4 ft. of the top screen has 2-in. round holes which permit pieces the size of stove-coal to fall through to a chute; pieces larger than 2 in. pass over the end of the screen to another chute. The stove-coal goes to jigs, *D*,

thence to rolls, *E* and *F*; and, after being broken to pea-size and smaller, to the main elevator-boot, *A*.

The large coal is hand-picked by six men and boys and the slate removed, after which it is sent to the rolls and the main elevators. The coal that drops through the top screen of the shaker, *C*, falls on to the second screen having $\frac{7}{8}$-in. holes, the chestnut-size passing over, and pea- and smaller sizes dropping

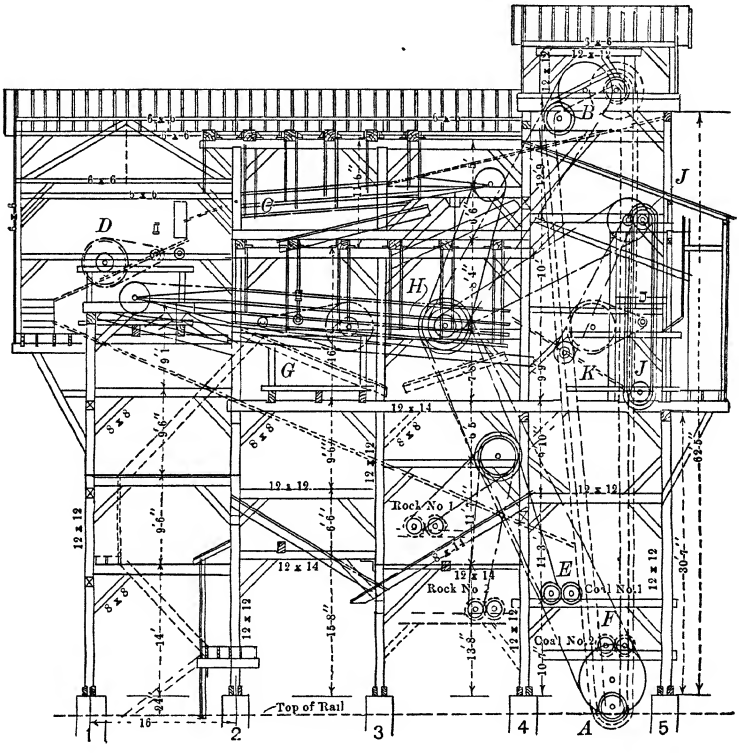

FIG. 5.—CAPOUSE WASHERY (PARTLY IN ELEVATION). LONGITUDINAL SECTION.

through to the lowest screen. The chestnut-size goes to jigs, *G*, thence to rolls, *E* and *F*. The bottom screen has $\frac{3}{32}$-in. holes which permit the fine coal-dirt, slush or culm (it is called by all three names) and mud to pass through to a trough which delivers to a settling-pond near the washery, where the stream spreads over a large, nearly level, area, and deposits the suspended materials. The pea-size and smaller sizes of coal pass over the bottom screen to a second shaker, *H*.

The shaking-screen is simple in construction, effective in action, occupies little space and needs few repairs. At the Capouse washery, each screen is suspended by $\frac{7}{8}$- by 8-in. ash boards, their upper ends bolted to overhead beams, and the lower to castings, which journal on bars passing under and supporting the screens. Two boards, comprising the hanger on each side, are set at an angle from the vertical, so that they act as braces and prevent the screens from swaying sideways. When suspended by rods, the screen travels between guides to insure greater steadiness. Both methods of suspension are used, the boards having the preference.

The shaker, *H*, consists of four tiers of screens, the top one having an area of 30 by 6 ft., the next lower 26 by 6 ft., and the two lower being 20 ft. long by 6 ft. wide. The coal, passing through this shaker, is separated into sizes as follows:—the top screen with 0.5-in. mesh allows the pea-coal to pass over, and No. 1 buckwheat and all smaller to drop through; the next screen, with 0.375-in. mesh, separates No. 1 buckwheat from the smaller sizes, the latter dropping through to the next lower screen with a $\frac{1}{4}$-in. mesh; this last screen makes No. 2 buckwheat or rice-coal; No. 3 buckwheat or barley passes over the lowest screen which has $\frac{3}{32}$-in. mesh, through which drops the fine coal to be carried by the wash-water to settling pond No. 2. The wisdom of keeping the mud from the shaker, *C*, separate from the fine coal of the shaker, *H*, when possible, will be more apparent as time goes on, and this fuel becomes valuable as material for briquettes or for burning as dust.

The three buckwheat sizes from the shaker, *H*, go direct to pockets, but the pea-coal must be cleaned of slate. After the pea-size leaves the top screen it passes down a chute, in which is a triangular device raised about 0.5 in. above the bottom, so as to allow flat pieces of slate to pass under while the coal goes to the elevator, *J*, and so to the jigs, *K*. After leaving the jigs, the coal passes through a Pardee spiral picker for further cleaning and thence to a pocket.

A number of features about this washery are deserving of special mention. The six jigs (of the Christ type and measuring 11 ft. by 5 ft. 4 in. by 6 ft. 9 in.) are driven by a 7- by 8-in. engine. The coal receives a reciprocating motion in a pan immersed in water, which action causes the slate to sink, while

the lighter coal passes out at the top. Generally, three jigs are sufficient to clean the coal, the others being held in reserve. The larger-mesh screens on the shakers are of steel; but those of $\frac{3}{32}$-in. mesh, on account of the small perforation, must necessarily have thin metal to prevent clogging, and therefore are made of bronze, in order better to withstand the action of the acid mine-water used in washing the coal. At the Capouse washery, the shaker, *H*, has, above the tier of screens, four overflow water-boxes, which are very efficient.[6]

The shaker, *C*, receives from 165 to 170 thrusts per minute, and the shaker, *H*, about 180. To re-break large coal to pea-size and smaller, two rolls are used, the roll, *E*, being 24 by 24 in., and *F*, 21 by 24 in. The two rock-rolls shown in Fig. 5 were used to crush slate, taken from the coal, to a size not larger than pea, which was then sent with the fine coal to fill old mine-workings, a method since abandoned at the Capouse washery.

As previously noted, a large quantity of water is most important for successful washing, and the supply for the Capouse washery is obtained from an adjacent shaft. A bull-pump raises water from the mines and delivers it to a reservoir near the washery, the pumping-equipment of which consists of three No. 10 Knowles pumps, 16- by 10- by 16-in. It is estimated that each pump furnishes 500 gal. per min.; two pumps raise water to the top of the washery, through their two 6-in. columns which connect at the top; the third pump supplies water for flushing the material into conveyors at the culm-bank. All water-pipes about the plant are at such an angle, that, when work stops, valves are opened and the water drains out, thus preventing the pipes from freezing-up in cold weather.

The machinery is operated by a 24- by 24-in. Dickson engine, running at 78 rev. per minute. The steam is supplied by

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[6] A similar shaker at the Bellevue washery is equipped with a different device. A pipe carries the water close to the coal on the top screen; and a piece of sheet-iron fastened to the pipe directs the water in a flat spray against the direction of the moving coal. This retards the coal and turns it over, thus facilitating the sizing and cleaning Four sprays, equally distributed along the length of the shaker, are used for this purpose. The shakers have a pitch of 1 in 12 in the direction of the flow of coal, and receive a thrust or reciprocating movement of 5 in. from the eccentrics connected at the upper end.

three fire-tube boilers, housed in a substantial brick building, situated at a distance of 500 ft. or more from the washery. The labor required to run the plant consists of from 40 to 50 men and boys, a larger number being needed in winter than in summer, to clean out railroad-cars, etc. The outside force includes a foreman in charge of the whole plant; 2 hose-men; 10 or 12 men on conveyor-lines; 2 men to run the conveyor-engines; 1 man at the elevator-boot; and 2 men at the settling-ponds. The force inside the washery is distributed as follows: one machinist or oiler; 1 carpenter or repair-man; 3 jig-runners; 8 slate-pickers; 1 engineer; 1 man at the head of the main elevator; 4 loaders; 2 car-repair men; 6 slate-dump men. In addition, there are, at the boiler-house, 3 firemen; 1 man to cart out ashes, and one man to wheel in coal. The Capouse plant has shipped coal since November 1, 1900, and during 1904 worked 182⅓ days of 9 hours each, producing 184,004.7 tons. The record for the washery was made in January, 1902, when 31,018 tons were produced in 262½ hours.

Other Plants and Practice.

The Nottingham Washery.—In the Capouse plant, which makes pea and buckwheat, the machinery for removing slate consists of 6 Christ jigs and 1 spiral picker, through which the large coal is cleaned before going to the rolls. A different method is followed at the Nottingham washery of the North American Coal Co., of Plymouth, a plant making 6 sizes of coal, from stove to No. 3 buckwheat (*i.e.*, barley). At the latter plant 11 Pardee spirals and 1 Emery picker are employed to remove the slate mechanically. There are also other important differences. The Nottingham washery contains 3 shakers and 3 pairs of coal-rolls. The large coal from the first shaker or mud-screen, after being hand-picked, is sent direct to the rolls, and finally cleaned of slate in the spirals just before going to pockets. The first or mud-screen sends pea-coal to pocket, the second shaker makes three sizes of buckwheat and the third shaker produces stove-, nut- and pea-coal. This plant employs, on an average, 58 men and 18 boys, and has a capacity of 100 tons an hour. The Nottingham culm-bank contains a considerable amount of large coal, which is not re-crushed as fine as at other plants.

The Schuylkill Washery.—This plant of the same company embodies features peculiar to the handling of culm-banks containing larger pieces of coal (or coal and slate) than either of those above noted. At the Schuylkill works, men with sledges break up the largest pieces at the bank before the material is flushed into conveyors. Before passing into the washery proper, the coal goes to a shaking-screen with two decks, the upper of which has 5.5-in. and the lower 2.75-in. mesh. Everything dropping through this shaker passes direct to the main elevator. The two grades of large coal, passing over the screens, go to separate chutes, where men pick out the slate; after which the coal goes to rolls, is broken to egg-size and smaller, and then passes to the main elevator.

The Delaware, Lackawanna and Western Washeries.—An interesting feature of these washeries is the mechanical method used for ascertaining the percentage of slate in every car of coal shipped. As a car is being loaded, samples of coal aggregating 10 lb. are taken at different intervals and thoroughly mixed; and 3 lb. taken therefrom are placed in a perforated copper pail. The pail is then suspended in an earthenware jar containing sulphuric acid, of a specific gravity half-way between that of coal and of slate. As a result, the coal floats on top and is skimmed off, while the rock and slate, sinking to the bottom of the pail, are withdrawn from the liquid and weighed. The weight of the impurities, compared with the weight of the 3-lb. sample taken, gives the percentage of slate in the coal.

Local Variations in Practice.—In some instances, particularly in the Schuylkill region, the culm-bank is loaded by a steam-shovel into mine-cars, which are hoisted up a plane to the top of the washery and then dumped. Here, the material may pass over bars, and the large pieces may be handled on a platform, as in breakers.

In many washeries, the "bony," or pieces of mixed coal and slate, constituting the "middlings" between clean coal and clean slate, are re-broken and sent over the screens a second time, thereby recovering a considerable quantity of good fuel.

General Remarks.

It is interesting to note that of the 13 coal-producing operations of the Girard Estate during 1903, 2 are classed as wash-

eries; yet of the 11 collieries, the production of 2 came, in 1903, almost entirely from culm-banks, and 6 others very materially augmented their output from this source. Thus the 2 washeries shipped 230,039.18 tons or a little more than 15 per cent., while coal reclaimed from culm-banks formed 30.7

TABLE II.—*Shipments of Coal from Washeries During* 1903.

Name of Company or Washery	Size of Coal								Total
	Egg	Stove	Nut	Pea	Buck-wheat	Rice.	Barley,	Culm	
	Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons	Tons
Scranton Coal Co (1904), Capouse Washery				9,483 12 (5 15%)	57,785 15 (31 41%)	41,112.13 (22 34%)	75,622 07 (41 10%)		184,002 47
Mt Pleasant Washery				13,725 13 (6 93%)	41,851 18 (21,11%)	51,320 17 (25 89%)	91,321 07 (46 07%)		198,217 55
Raymond Washery				14,755 16 (7 48%)	54,546 16 (27 64%)	52,227 01 (26 46%)	75,816 18 (38 42%)		197,344 51
North American Coal Co (1903) Schuylkill, No 1		8,400 90 (4 83%)	17,082 55 (9 81%)	25,472 85 (14 63%)	63,321 85 (36 38%)	48,514 65 (27 87%)	11 164 55 (6 42%)	129 70 (0 06%)	174,087 05
Raven Run Coal Co (1903)			5,390 70 (9 64%)	10,084,20 (18 02%)	22,157.70 (39 60%)	18,320,25 (32 74%)			55,952 85
Girard Colliery (1903)	169 75 (0 33%)	1,403 85 (2 71%)	4,691 30 (9 06%)	16,725 30 (32,32%)	16,951 75 (32 76%)	11,808 85 (22 82%)			51,750 80
D, L & W R R Coal Dept (1904)					196,250 00 (25%)	274,750 00 (35%)	314,000 00 (40%)	..	785,000 00
Total									1,646,355 23

per cent. of the total shipment of 1,515,213.14 tons, from all the operations of the Estate.

The proportions of the various sizes of coal found in culm-banks varies in the different banks and also at times in the same bank. Table II. shows the shipments in 1903 from a

number of washeries throughout the anthracite-field, and gives a fair idea of what is generally reclaimed. While this table gives the coal produced from banks, it does not generally indicate the sizes going to the washery; for, in most cases, the larger pieces are re-broken. For example, the Delaware, Lackawanna and Western Coal-Department makes nothing larger than buckwheat-size at the washeries, everything in the banks being broken to that size and smaller.

Washery-coal appeals to the operator and the engineer, as well as to the consumer of fine coal, particularly in cities. The operator sees in these large accumulations from former mining-operations a great quantity of coal readily available for quick shipment when occasion demands. During the anthracite strike of 1902, these washeries, being comparatively easy to operate, and requiring a relatively small number of men (mainly unskilled), were for months the only productive source of hard coal. Large shipments from these plants were made for some time after the mines resumed; and for this cheap supply of smokeless fuel there was a great demand from steam-users in many neighboring cities. From an engineering standpoint, the reclaiming of coal from culm-banks is gratifying, because it recovers value from the great waste which attended the early mining of anthracite.

The Limestone-Granite Contact-Deposits of Washington Camp, Arizona.

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Introduction.

WASHINGTON CAMP, in Santa Cruz county, Arizona, is a small and little-known mining-district situated on the lower, eastern slope of the Patagonia mountains, about 20 miles east of Nogales and a like distance south of Patagonia Station on the Sonora railroad, which connects at Benson, 83 miles from Nogales, with the main line of the Southern Pacific. This district is also about 4 miles north of the international boundary, 35 miles west of Bisbee and 40 miles north of Cananea, in Sonora. The topography of the district, which lies at a general elevation of 5,500 ft. above the sea, is only very moderately rugged, and presents no obstacles to mining-operations.

Although some of the claims of the camp, including the Pride of the West, Belmont and Holland, were extensively worked for silver 25 years ago, they passed, at moderate depths, as in so many other districts, out of the argentiferous lead carbonate and sulphide, into zinc, copper and iron sulphides; and for two decades the camp was abandoned and almost forgotten. In recent years, however, its apparent possibilities as a copper-producer have led to a revival of mining-activity; but not, as yet, with conspicuous success.

Although economically relatively unimportant, the deposits of Washington Camp are, mineralogically and structurally, nevertheless, typical examples of ore-bodies developed in connection with the garnet ledge now recognized as a normal feature of granite-limestone contacts; and, in the opinion of the writer, this is an instance where a minor example is yet essentially normal and capable of throwing important light upon the origin and genetic relations of the type.

I visited Washington Camp in 1901, and again in 1902; and have devoted, in all, about a week to the study, in the field, of the geologic relations of its ore-deposits, adding, incidentally, a suite of the rocks and ores to the economic geological collections of the Massachusetts Institute of Technology.

General Geology.

Washington Camp consists (geologically) of an irregular area of limestone and quartzite of uncertain age, about 7,000 ft. in extreme length north and south, and 3,000 ft. in maximum breadth east and west. This body of sediments is bordered on all sides by igneous rocks—granite and porphyry; and it may be regarded as an island in the sea of granitic rocks composing the main part, at least, of the Patagonia range. The granite and the porphyry (which is clearly a somewhat-later phase of the granite) are newer than the sedimentary rocks, and have been erupted through the latter; and the area in question is simply a remnant of the original formation which was so deeply engulfed by the igneous rocks that it has survived the extensive erosion which has long since swept away the rest of the sedimentary cover of the granite over an area of many hundreds of square miles. That the erosion has been extensive we have also positive proof in the coarsely crystalline character of most of the granite and in the highly metamorphic character of the limestone, even at points remote from the border of the granite. The sedimentary rocks are not now absolutely continuous, but several detached masses occur in the granite along the eastern border of the main area; and the latter is more or less completely divided towards its western margin by several large north-south dikes of granite. Although no fossils have survived the metamorphism of the limestone, by which its geological age might be determined, there is no reason to doubt that it is a part of the great Paleozoic limestone-formation, so characteristic of many of the mining-districts throughout the entire Rocky Mountain region.

The strata are highly inclined at all points, but the dip varies greatly in direction and amount; the prevailing dip, however, is to the west, at angles of from 30 to 90 degrees, but mostly above 60 degrees; while toward the eastern border the dip, at a few points, is reversed, or easterly, at similarly high angles;

and, in general, it may be said that the stratification is highly disturbed, with, in some cases, abrupt and extreme variations in strike and dip.

Beginning on the west side of the belt we have:—first, a band of quartzite from 100 to several hundred feet wide, which may, tentatively, be regarded as of Cambrian age. Following this, and magnificently developed in Washington mountain, the highest point in the district, is a massive limestone, characterized by numerous narrow bands and lenses of chert. Dividing the limestone on the eastern slope of Washington mountain is a second band of quartzite, at least 100 ft. thick. This is followed by a broad band of blue, crystalline limestone, or marble, extending well down toward the base of the mountain. Still farther east, this limestone is interstratified with one or more heavy beds of chert, which, having commonly a somewhat crystalline character, are usually called quartzite. On the eastern slope of the mountain are also to be seen the great dikes of granite, three in number, previously referred to, the most easterly of these dikes forming the hanging-wall of the Pride of the West mine. This brings us approximately to the middle of an east-west section of the sedimentary series; but farther east the limestone is comparatively free from chert bands, presenting extensive bodies of gray to white, crystalline marble in which the stratification is often very indistinct.

It thus appears quite certain that the section is not repeated or folded upon itself; and, notwithstanding the prevailing westerly dip, it is probable that the western quartzite is the oldest member of the series; and the entire formation may, therefore, be regarded as partly inverted.

The sedimentary series is, apparently, conformable throughout; and one is tempted to correlate the western or assumed basal quartzite of the Washington Mountain section with the Bolsa quartzite of the Bisbee district, described by Ransome.[1] The latter, however, with a maximum thickness of 430 ft., is seen to rest unconformably upon the Pinal or Algonkian schists; while the former, though not so thick, is everywhere in igneous contact with the granite, and it is improbable that its full normal thickness is now exposed. The limestone fol-

[1] *Geologic Atlas of the United States, Bisbee, Folio No* 112, *U. S. Geological Survey* (1904).

lowing this quartzite and forming the main mass of Washington mountain, becomes, then, the equivalent of the Abrigo limestone of Bisbee, which has a thickness of 770 ft. These two limestones are certainly comparable in thickness and in the prevalence of chert; but the Washington Mountain limestone is more massive and, apparently, non-fossiliferous, due, possibly, to more intense metamorphism; while the Abrigo limestone is definitely proved by its fossils to be of Middle Cambrian age. In each district this older limestone is followed by a second, white quartzite; but this is only 8 ft. thick at Bisbee, and fully 100 ft. on the eastern slope of Washington mountain. Above this quartzite, at Bisbee, come several thousand feet of limestone, including the Martin limestone (Devonian), 340 ft.; the Escabrosa limestone (Lower Carboniferous), 800 ft.; and the Naco limestone (Upper Carboniferous), 1,500 to 2,000 ft. These Upper Paleozoic limestones of Bisbee may, perhaps, be correlated tentatively with the Washington Camp section above the parting quartzite; and I have been inclined to regard the latter as a general equivalent of the Harding sandstone in Colorado.[2] The heavy beds of chert in the middle part of the Washington Camp section appear to be lacking at Bisbee.

From the northwest border of the area of sedimentary rocks, at least three great dikes of granite extend southward along the strike of the limestone. The most easterly dike, fully 100 ft. wide, forms the hanging-wall of the upper ore-body in the Pride of the West mine, and is separated by several hundred feet of chert and limestone from the second dike, which is proved by a cross-cut tunnel to be over 150 ft. wide. These two dikes converge southward and become one. The united dike can be traced across Double Standard gulch, passing west of the Holland mine; and it probably continues until it crosses the southern border and rejoins the main body of granite on the Belmont claim or the Lead King claim. The second dike, on the eastern slope of Washington mountain, is separated by a broad band of blue, crystalline limestone and the parting quartzite from the third dike, which is at least 100 ft. wide, but appears to die out southward before reaching Double Standard

[2] *Geologic Atlas of the United States, Pike's Peak, Folio No. 7, U. S. Geological Survey* (1894).

gulch. Above this dike, the very massive crystalline limestone, with innumerable lines and lenses, but no heavy beds, of chert, extends to the summit and to the contact with the basal quartzite on the west slope.

In further comparison with the Bisbee district, it may be noted that the garnet ledge is more prominently developed than at Bisbee, and that faulting is relatively unimportant at Washington Camp, so that there appears, in general, to be little difficulty in tracing a particular horizon from end to end of the sedimentary island or inclusion in the granite.

The granite varies from a normal biotite-granite to a well characterized granodiorite, with dikes, also, of a highly acid, aplitic variety. The porphyry seems to show a similar range in composition, and occurs chiefly, at least, as dikes, cutting both the granite and the sedimentary rocks, although, probably, essentially contemporaneous with the former.

The metamorphic influence of the inclosing and intrusive acid igneous rocks is seen, not only in the crystallization of the limestone to form marble, and of the chert bands to form quartzite, but also, and very strikingly, in the development in the less-pure layers of the limestone of enormous bodies of green garnet (grossularite), and other secondary silicate minerals. The original limestone may safely be assumed to have contained silica, clay and iron oxide, as the chief impurities; and from the more-impure beds of limestone, during the process of metamorphism, the garnet-zones have been developed. These zones are commonly from 50 to 100 ft. or more in breadth; and they are found not only along the limestone-granite contacts, but also running in a north-south direction through the middle of the limestone remote from the granite, wherever, we may suppose, the original composition of the limestone favored their development, and chiefly along lines passing longitudinally through the Pride of the West, Holland, Double Standard and Annie belts of claims. The garnet rock, again, is not a constant feature of the contact, its absence at the north end of the district, on the eastern border and across a part of the south end, as also, in general, along the granite dikes, being especially noteworthy; but it is, apparently, developed only where the limestone was sufficiently impure to furnish, in both quality and quantity, the material required for the

formation of the garnet and related minerals. This selective relation is particularly obvious at the south end, where the contact cuts squarely across the strike of the limestone, and the garnet-zone is developed only on the less-pure beds of limestone. It is a very significant fact, in this connection or in its bearing upon the origin of the garnet-zone, that, along that part of the western border of the district where the basal quartzite intervenes between the granite and limestone, the garnet-zone is found between the quartzite and limestone, and not along the contact of the quartzite and granite.

The granitic rocks not only completely surround the sedimentaries, but, at some depth, they must underlie them, so that a vertical shaft at any point would, eventually, pass out of the limestone into the granite; and it is altogether reasonable to suppose that this lower contact, at least equally with the lateral contacts, is characterized by the garnet-zone.

The fact that the metamorphism of the sedimentary rocks is not confined to the borders, but is, in general, somewhat uniform over the entire area, varying only with the original composition of the limestone, and the absence, at most points, of a fine-grained or compact border in the granite itself, show, not only that these rocks were very deep-seated at the time of the intrusion of the granite, but also, apparently, that the granite underlies the limestone now at no very great depth; although the Westinghouse shaft, on the extreme eastern margin of the limestone, has failed to reach the bottom at a depth of 650 feet.

Ore-Deposits.

Although having, in general, more or less the forms of veins, the ore-deposits are not, to any important extent, true veins; but are better classed as substitution-deposits or replacements in the limestone. Among their more-striking characteristics are the following:—

(1) They are entirely confined to the sedimentary rocks, and chiefly to the limestone, and have not been observed in any instance to extend ever so slightly into the surrounding granite. This seems to force upon us the conclusion that the ores have not been derived from the granitic rocks, and have not, therefore, come from a great depth in the earth.

(2) Save where the contact is transgressive, they correspond closely, but not always exactly, with the limestone in dip and strike, and are at all points clearly to be recognized as replacements of the limestone.

(3) Where not accompanying the limestone-granite contact, they usually occur along the contact of the limestone with a principal bed of chert.

(4) They are, in general, very intimately associated with the garnetiferous zones, which undoubtedly represent what were originally exceptionally-impure members of the limestone series. This association is so constant that the garnet has come to be recognized as a fairly-reliable indication of the occurrence of the ores; and the garnet rock and the ores are often very intimately commingled, the garnet forming, in most cases, the principal gangue of the metalliferous minerals or ores.

(5) The ore-body accompanying a contact garnet-zone is always on the inside of the zone, that is, between the main body of the garnet ledge and the limestone, and not between the garnet ledge and the granite.

The ores include, chiefly, chalcopyrite and sphalerite, with, at the present time, very subordinate amounts of galena. Secondary ores are relatively very unimportant, and are now pretty well worked out. The oxidized copper-ores, including cuprite, the carbonates and chrysocolla, occur but sparingly, and the secondary sulphides (bornite and chalcocite) are rarely seen. Although the copper-ore (chalcopyrite) ranks first in value at the present time, the zinc-ore (sphalerite) predominates in the deposits, tending to become relatively more important with depth; and an important output of zinc would seem to be among the possibilities for this district.

Metamorphism of the Limestone and Chert.

The crystallization of the purer phases of the limestone to form white to gray saccharoidal marbles, and of the chert (in part) to form non-clastic quartzite are normal phenomena, demanding no special discussion. In part, however, the metamorphism of the chert has gone far beyond the degree here indicated. Thus, in the southwestern part of the field, on the Lead King and Belmont claims, bordering, but not penetrating, the granite, is a compact body of coarsely crystalline quartz

fully 100 ft. wide and extending, northward, in the direction of the strike and away from the granite, at least 300 ft. and possibly much farther. In large part this body is essentially structureless, consisting of massive, vitreous quartz; but enclosing, also, many more or less distinct crystals of quartz ranging in size up to at least 2 ft. in length and 5 in. in diameter, and occurring to a considerable extent in radiate groups. A shaft sunk 20 ft. into this mass disclosed nothing but pure quartz in a plexus of gigantic crystals. The outcrops in this part of the field are less continuous than could be desired; but the facts clearly indicate that this remarkable body of nearly pure crystalline quartz is not in any sense a vein, or a pegmatitic phase of the granite; but rather that it marks an extreme degree of metamorphism of a broad band of chert, the quartz being in the line of strike of such a chert horizon, and seeming to grade longitudinally into it. Although an extreme, it is by no means an exceptional or unparalleled phase of the metamorphism, except, perhaps, in the magnitude of the resulting body of crystalline quartz; for coarsely crystalline quartz, sometimes in stellate groups, is a constantly recurring feature of the garnet-zones and ore-bodies; and it is probable that a detailed study of other chert bands in the vicinity of the granite would show that a gradation from the normal to the most highly-metamorphic forms of the chert is a general fact. Unfortunately, no economic interest attaches to the chert; and hence exploitation has added but little to our knowledge of its occurrence.

No correspondingly coarse crystallization of the limestone, on a large scale, has been noted; although, near the igneous contacts, and in the garnet-zones, it is distinctly sparry, with cleavage faces of calcite from one to several inches across. The chief interest of the metamorphism of the limestone is found, of course, in the secondary minerals; among which the pale yellowish or brownish-green lime-alumina garnet (grossularite) largely predominates, in finely to coarsely crystalline massive aggregates. The form is dodecahedral, and the individual crystals rarely exceed 2 in., and are commonly less than 0.25 in. in diameter. Associated with the garnet, in some parts of the field, is more or less epidote in slender, green prisms, with, possibly, some vesuvianite and various forms of amphibole, including actinolite and tremolite, the latter being

most abundant and often very intimately associated with the ores. Quartz, in coarse and irregular masses, is usually, as previously noted, rather a prominent feature of the garnet-ledge, which, because of the hard and resistant character of its component minerals, forms bold and rugged outcrops, made, in detail, more rugged by the solution of the included sparry calcite and the weathering-out of the ores. The crystalline iron-ores (magnetite, etc.), and the jasperoid forms of silica often associated with the garnet-zones of other districts are practically wanting in Washington Camp.

A rather specially interesting phase of the metamorphism of the limestone, though not as yet identified as a feature of the garnet-ledge or the ore-bodies, is massive lime silicate or wollastonite occurring commonly as a reaction-zone, bordering layers and nodules of chert in those portions of the cherty limestone nearest the granite, or within several hundred feet of the contact. The relations are very clear, the chert masses, often with frayed and disintegrated margins, being separated from the enclosing crystalline limestone (white marble) by zones from one to several inches broad of white, massive wollastonite, which, like the chert, is left in high relief on the weathered surface of the limestone. That the silica of the chert has replaced the carbon dioxide of the limestone is obvious.

The geological interest of the metamorphism of the limestone centers in the source of the materials of the garnet and other secondary silicates. Although some recent writers have regarded the garnet-zones as intrusive igneous masses, or, possibly, as differentiation-products of the granite magma, the general consensus of opinion, at the present time, is that they are normal products of the contact-metamorphism of the limestone. No other view can be made to fit the facts of Washington Camp; and the question of vital interest is, as to whether the limestone has furnished all or only a part of the ingredients of the garnet and other silicates, the necessary elements being approximately the same for them all. It is a significant fact that they are practically all lime-silicates; and apparently no one accepting the metamorphic theory doubts that the lime is wholly indigenous, that is, was furnished exclusively by the limestone. All the other required elements are normal im

purities of limestone, including silica, alumina, magnesia and iron. The first two, with a little iron, suffice for garnet and epidote; and the addition of the magnesia makes the amphiboles a possibility. It is certainly a very exceptional limestone which does not contain the small amount of magnesia, called for in this case; and surely we have no need and no warrant to go outside of the limestone for such a normal, abundant and stable or insoluble impurity as alumina. The *onus probandi* clearly rests upon those who hold to the contrary view. Similarly, ferrous carbonate, not to mention the oxides and sulphides of iron, is a nearly universal constituent of limestones, and a ready source of iron for the metamorphic ferruginous silicates, as well as for magnetite and sparry siderite.

Finally, silica, including free silica, both clastic and organic, and the combined silica of kaolin and other silicates, is, perhaps, the most important of all the non-essential elements of limestone. The ratio of silica to alumina in kaolin is less than in grossularite; but original free silica may easily make good the difference; and any excess of lime may or may not be eliminated by solution. The sufficiency of the free silica is indicated by the fact that, in many analyses of limestones not visibly siliceous, the total silica is far in excess of the amount required to form kaolin with the alumina. The averages of 42 analyses of limestones made in the laboratory of the United States Geological Survey,[3] including all those for which both the silica and alumina are given separately, are: SiO_2, 8.514, and Al_2O_3, 1.077 per cent., the ratio being very nearly 8:1.

Analyses of unaltered limestone are, of course, devoid of special significance in this connection, unless it can be shown that they represent closely-adjacent portions of the same beds which have, locally, suffered metamorphism by silication. Limestones, more than most other kinds of sediment, are, in successive beds, subject to marked and abrupt changes of chemical composition, due to fluctuations in the proportions of the normal (organic) and the accessory (organic, clastic and chemical) constituents; and gradations into beds of chert, shale and even sandstone are not uncommon.

In view of these considerations, further argument might almost be deemed superfluous, at least as regards the adequacy

[3] *Bulletin No* 228, *U. S. Geological Survey,* p. 331 to 336 (1904).

of the limestone, considered as a source of the raw materials of the contact minerals. But some of the arguments based upon the structural relations of the limestone are also peculiarly cogent. For instance, the garnet-zone is, as previously noted, by no means a constant accompaniment of the granite-limestone contact; and in strength and persistence it obviously varies inversely as the purity of the limestone, being very weak or wholly wanting where the purer beds of limestone, the typical white or light gray marbles, meet the granite. This selective relation is very noticeable across the ends, and especially the broad southern end, of the limestone island, where the granite contacts successive beds of limestone of varying composition, and fails to develop a garnet-zone wherever the limestone is of notable purity. Besides the variable and intermittent character of the garnet-zone along the contact, we must take cognizance of the very persistent garnet-zones, which, disregarding the granite contact, follow each a particular bed or horizon of impure limestone longitudinally through the district; and of special interest and significance among these is the garnet-zone at the base of the limestone, in the siliceous and argillaceous beds of passage between the basal quartzite and the limestone, and separated by the quartzite, from 100 to 200 ft. thick, from the western granite.

Among those who accept the metamorphic origin of the garnet-zones of granite-limestone contacts, Professor Kemp is the foremost exponent of the view that the granite has contributed not only the heat or thermal energy, but also, in large part, the material, required for the formation of the garnet and related silicates. Apparently, Professor Kemp would look to the granite or acid plutonic for everything needful, except, perhaps, the lime; although it may be noted that the plutonic rock is, in general, rich in lime as well as alumina, and the transfer of the former base would be the simpler chemical problem. However, the lime is not needed; and in my opinion it has not been proved that we need look beyond the sedimentaries for any of the raw materials of the garnet-zone. To simplify the phraseology, and, at the same time, to emphasize the vital contrast of the two explanations of the garnet-zone now under consideration, we may restrict the term "metamorphic" to the theory which derives all the material from the

limestone and refers to the granite only for the agents—heat and, possibly, some water, and designate as "metasomatic" the theory which derives an important and essential part of the material, as well as the agents, from the granite.

Except where the limestone is very impure, the lime will naturally be in excess of the amount required to form the garnet and other secondary lime-silicates; but that this is, in no sense, a bar to the metamorphic theory must be obvious when we consider the possibility of disposing of the excess by either contemporaneous or subsequent solution or re-crystallization. An instructive illustration, on a minor scale, is offered by the writer's observations on the calcareous Lower Cambrian slates of the Boston Basin. In this instance, the calcareous element assumed originally the form of calcareous concretions or clay stones; and when, in later Paleozoic times, the strata were invaded by the granitic series and suffered metamorphism, the outer part of each calcareous concretion became a shell of impure epidote. In many cases, the silica and alumina within this shell have been exhausted in the formation of the epidote, and the residuary calcium carbonate has re-crystallized, forming a core of white marble in the epidotized calcareous concretions of a red slate.

If we regard the granite as an important or, possibly, principal source of the materials of the garnet-zone, as we may for the sake of argument, it gives to the contact-relations and character of the granite special significance and interest, since it is not easily credible that the granite might transfer to the limestone a large part of the material of the garnet-zone and still remain entirely normal, giving no sign of its loss. As a matter of fact, both the granite and porphyry, so far as can be determined by macroscopic observations, are unchanged in texture and composition, and entirely normal on and near the sharply defined line of contact. In other words, the granite shows no reaction-zone, and there is absolutely nothing to suggest the leaching, depletion or mineralization of either formation by, or at the expense of, the other. These statements are applicable alike to the main body of the granite and to the granite dikes.

If the silica and alumina have been derived from the granite, and the limestone has furnished only the lime, magnesia and

iron, the garnet-zone should be a constant feature of the contact; or, at least, there is no apparent reason why it should fail, as it does, just where silica and alumina are wanting in the limestone. Again, the metasomatic theory affords absolutely no explanation of the essentially similar and equally strong garnet-zones developed independently of the granite contacts, in the limestone, or between the limestone and the basal quartzite; for surely we cannot suppose that material in liquid or gaseous solution would pass through hundreds of feet of solid limestone or quartzite, to react with the limestone of certain definite and narrow horizons.

Professor Kemp has minimized the normal ground-water of oceanic and meteoric origin, and maximized the magmatic water emanating from plutonic and intrusive magmas before and during refrigeration, as regards both volume and geological efficiency, and especially as regards their efficiency in the formation of veins and ore-deposits. The only definite and positive indication that the magmatic water is abundant is afforded by the copious exhalations of steam accompanying volcanic eruptions. But the argument that this is all, or even chiefly, magmatic water is far from conclusive. Its deposits certainly do not indicate it. A distinguishing feature of magmatic water is supposed to be its heavy burden of dissolved elements, which, combined to form various mineral species, must be left behind, on or in the lava, as the water escapes into the atmosphere. Except, perhaps, in, or in the immediate vicinity of, vents of long-continued solfataric activity, these deposits are usually conspicuous by their absence. The water promotes the liquidity of the lava, and thus, in a sense, holds in solution the entire body of the magma, and, although diminishing with the pressure, like the gases dissolved in molten metals, it manifests no marked tendency to escape in advance of the general refrigeration of the magma; and then, in general, it leaves behind no deposit other than the normal lava.

The argument for the sufficiency of magmatic water requires us to assume that, below the superficial, shallow and wet zone of the vadose circulation in the earth's crust, is a deep and relatively arid or anhydrous zone, the upper part of which has been discovered by numerous mines and borings, and below

that, in the plutonic regions, where magmas are developed, a third zone which, like the vadose, is highly hydrated, but the water of which is original or primitive, and has never formed a part of the hydrosphere. The intermediate, relatively dry zone, comprising the main body of the earth's crust, is composed, for an average thickness to be measured by miles, of sedimentary rocks, which must have once been in a state of supersaturation, but which have suffered extensive dehydration under the combined influence of long-continued heat and pressure. How it is that the water of the plutonic zone, exposed for an immensely longer time to far higher temperature and pressure, has escaped expulsion has not been explained. Further, it is virtually asserted that the volcanic chimney belongs to that bad class which will not "draw"; in other words, that the subterranean chimney does not create an in-draught of the ground-water analogous to the in-draught of air to a sub-aërial chimney. This anomaly, if true, also awaits explanation.

For the magma, the conditions are dominantly thermal; but for the resultant lava they are, or soon become, dominantly aqueous. The component minerals then prove to be more or less unstable compounds, and are subject to alteration by the in-drawn ground-water, the solvent and decomposing action of which is promoted, rather than retarded, by the high temperature still prevailing. In other words, solfataric waters, by which alone important deposits are made within the range of observation, are probably not, chiefly, magmatic waters struggling up from plutonic depths; but, rather, they are to be regarded as marking the first and most vigorous attack of the normal ground-water upon the intrusive and effusive igneous rocks, and hence as positive proof that the chimney does draw at this stage, if not earlier.

In any speculation as to the volume of water set free by the freezing of a magma under plutonic conditions, it is important not to forget the shrinkage due to crystallization and cooling, or that the liberated water, though above the critical temperature, may yet have the density of the liquid, or that there exists a real affinity between this water and the magma residuum, as so clearly proved by the phenomena of pegmatite. It is the excess water, if there be any, that concerns us now; and its nat-

ural avenue of escape, it would seem, should be upward, rather than lateral.

The picture of a copious exudation of magmatic water which, reinforced by various mineralizers and overladen with a large variety of elements, actively invades and alters the enclosing terranes by metamorphic and metasomatic processes, is not easily visualized, in view of the plain, every-day facts of the case. In the vicinity of Boston, and extending throughout eastern Massachusetts, the coastal district of New England and the maritime provinces, are hundreds of miles of contact of granitic rocks, not to mention a vast net-work of acid and basic dikes, intrusive in Cambrian and other early Paleozoic sediments. These sediments exhibit various degrees and kinds of metamorphism; but very seldom indeed do we find in them elements which may not fairly be regarded as original. Fluorite and other minerals regarded as specially indicative of the presence and agency of the so-called mineralizers are found chiefly in the igneous rocks, and have not migrated into the sediments. Apparently, heat is the one important contribution of the igneous rocks; and the normal ground-water, stimulated or energized by this heat and acting on the original elements of the sediments, has done the rest. Even quartz-veins and segregations, excepting those of pegmatitic origin, are comparatively rare accompaniments of the plutonic contacts of this region, and where occurring may usually be proved to antedate (as in the case of the auriferous veins of Nova Scotia) or postdate the development of the contact.

Especially difficult of visualization is the picture of the magmatic water gushing forth in so great volume that, merely by the deposition of its excess load, it may build a garnet-zone 100 ft. thick, equal to 100 cu. ft. of garnet and the emission of many thousand cubic feet of water for every square foot of the contact. The magma must, indeed, be highly hydrated to meet such a demand, and yet it is now of strictly normal character up to the sharply defined contact.

The development of the garnet-zone, whether by metamorphic or by metasomatic process, must have been centripetal with reference to the limestone, at least if we are to look to the limestone for the lime; necessitating, according to the metasomatic theory, the transfer of the silica and alumina and

other imported elements required for the inner part of the zone through the outer part. Also, the refrigeration or crystallization of the magma to form the granite must have proceeded centripetally or away from the contact, thus opposing a barrier of steadily increasing thickness to the emission of the magmatic water. In other words, the water liberated by the crystallization of the magma is forced inward, where it is needed to maintain the fluidity of the magma residuum.[4]

Origin and Relations of the Ore-Deposits.

The ore-deposits of this district clearly belong to certain more or less well-defined zones in the limestone, which may or may not follow granite-limestone contacts, but which are, in general, characterized by a more or less marked development of the garnet-ledge. The relations of the ore-bodies to the garnet-zones are very intimate and irregular, and the garnet and other secondary silicates, together with a limited amount of quartz and sparry calcite, constitute the normal gangue of the ores. But although we may regard the garnet-ledge as, in a general way, favorable to the occurrence of ore, some important ore-bodies are devoid of garnet; and the garnet-zones are at some points devoid of ore, or the ore occurrences are very limited and sporadic. Where associated with garnet-zones following the granite-limestone contact, the normal position of the ore, as previously stated, is, clearly, on the inner margin of the zone, facing the limestone and not the granite. The ore-bodies are, practically, never vein-like in form or structure; and they are devoid of true walls, since they clearly antedate all shearing and fracturing of the formation. The contact of the ores, alike with the limestone and the garnet, is often sharply defined, but always highly irregular; and, in the association or grouping of the ores, there is nothing even remotely suggestive of crustification, banding or comb-structure, or deposition in open spaces of any kind. Obviously enough, the ores, as we now have them, are due to a metasomatic impregnation and replacement of the limestone against and in the massive garnet-ledge; and the questions of special geological interest are, whence? and how? That is, what is the original source of the ores? and how were they concentrated?

[4] Origin of Pegmatite, *American Geologist*, xix., 170 (1897).

We cannot avoid the conclusion that the ores have come from either the limestone or the granite. Nowhere in the district has the slightest trace of ore been found in the granite. The ore rarely contacts the granite, and then only sparingly or sporadically, its normal position being between the garnet-ledge and the limestone, and irregularly impregnating both. The most persistent and strongest ore-bodies, again, are associated with the non-contact garnet-zones, which are, in part, far removed from the nearest border of the granite. In no instance has it appeared possible to correlate the ore-bodies with antecedent fissures, which might, conceivably, have served as channels of supply from underlying granite. The demonstrated faults of the district are clearly newer than the ores; and the latter sometimes exhibit beautiful slickensides where traversed by shear-planes and displacements.

The main body of the limestone, apart from the garnet-zones and ore-deposits, is, apparently, as barren of ore as the granite; and accepting either of these formations as the source of the ore, forces the conclusion that the processes of segregation and concentration have been singularly complete; although it is, of course, possible that refined analysis would prove the presence of zinc and copper where none are apparent to the eye. The plain indications are that, during the metamorphism of impure and, presumably, metalliferous beds of the limestone to form the garnet-zones, the metallic sulphides contained in these beds, and, possibly, in large volumes of the adjacent strata, were segregated by metasomatic process along the common boundary of the garnet-zone and the limestone.

As previously noted, Washington Camp is undoubtedly an outlier, isolated by igneous intrusion and erosion, of the great series of Paleozoic limestones in which are found a very large proportion of the ore-deposits of the Rocky Mountain region and the Pacific coast, as well as the widespread and rich zinc- and lead-deposits of the Mississippi valley, the last-mentioned district having been, from the beginning of Paleozoic time, remarkably free from every phase of vulcanism, and having suffered as little deformation as any part of the continent.

It appears difficult, in view of these considerations, to find any warrant for doubting that this great limestone-series, or some part of it, is normally and originally metalliferous; or

that, stimulated by intense and long-continued igneous and metamorphic agency (which was not required in the Mississippi valley), the circulation of the normal ground-water has proved equal to a more or less complete concentration of the metallic contents of the limestone.

Structural Details.

It is proposed to give here some local observations, which, although not conveniently included in the foregoing discussion, are of interest in their bearing upon the general theory of the district.

West Contact.—Beginning at the north end, a shaft on the Kansas claim, 150 ft. from the limestone-quartzite contact and 100 ft. deep to water-level, with about 200 ft. of drifting, shows mainly pyrite, with subordinate chalcopyrite, galena and blende and abundant quartz gangue. The main ore-body is vein-like in form, but without walls, and clearly a replacement in the limestone, with many isolated bunches or pockets of ore from 3 in. to 3 ft. or more in diameter, and usually parallel to the main ore-body and the bedding of the limestone. The garnet-ledge is not developed here; but a feature of special mineralogical interest is found in the pseudomorphic cavities due to the oxidation of the pyrite.

Next, south of this, on the New York claim, where the garnet-ledge is also wanting, a shaft 205 ft. deep has developed, at a distance from the quartzite-contact, one large and one small irregular ore-body, carrying good values of lead and silver above the water-level.

· Between the New York and Maine claims, the quartzite is broken or sharply flexed, being offset to the west several hundred feet, on the northern slope of Washington mountain; and the garnet-ledge is developed on the blending contact of the quartzite and limestone. Mingled with and following the garnet is the ore-impregnated limestone. All along this western contact the reaction-zones of wollastonite are a nearly constant accompaniment of the chert lenses and nodules in the limestone; but this feature gradually dies out as we recede from the granite.

On the Ella claim, crossing the upper western slope of Washington mountain, the basal quartzite is well developed, with a

breadth of from 100 to 200 ft.; and, as before, it separates the garnet-ledge, about 50 ft. wide, from the granite. The ore, which runs largely to black sphalerite, in part, admirably crystallized, occurs chiefly in the inner part of the garnet-zone, forming an irregular, weak or fragmentary body, accompanied by some striking stellate groups of quartz crystals.

On the contact claim, crossing the hill at the head of Bonanza gulch, this section is repeated from the granite through the quartzite and the ore-bearing garnet-zone to the limestone. But, although the garnet-zone is strong, the ore is weak and does not form continuous bodies. These conditions recur, also, on the Montezuma claim, which marks the southwest corner of the district; but the basal quartzite is here distinctly ferruginous and carries low values in gold.

On the Lead King claim, at the extreme southern end of the district, the granite is well exposed in two tunnels driven to cut the contact. Although of a highly acid, and, in the main, essentially normal character, it is, in part, also, more or less pyritiferous, the pyrite occurring chiefly, but not wholly, in the seams. No other instance of mineralization of the granite has been observed.

Eastern Contact.—Toward the southern end of this contact is the chief occurrence of porphyry which appears to be somewhat later than the granite and of rather more acid character; but, so far as observed, does not differ from the granite in its relations to the limestone and the ore-bodies. The eastern garnet-zone follows the contact somewhat continuously across the San Antonio and Duquesne claims to the Bonanza claim, on which is located the Westinghouse shaft, 650 ft. deep. The shaft starts in the porphyry; but all the lower part is in coarsely crystalline white limestone, and the bottom is said to be 65 ft. from the porphyry, proving that the contact overhangs the limestone a little. Farther north along this contact, the garnet-zone and ore-bodies are wanting, and we pass abruptly from the granite or porphyry to the gray to white marble, which is uninterrupted for a breadth of 1,000 feet.

North of Washington Post Office the contact is easily traced, and where it is crossed by the road for the last time it is well exposed in a cutting, showing normal granite against white crystalline limestone, with no signs of a garnet-zone, although a prospect hole shows a thin line of ore, while a little farther

north a line of prospect holes shows that the contact is there more heavily mineralized.

Central Ore-Zones.—These zones practically begin with the Pride of the West claim, in the latitude of Washington Post Office. This property, which produced a large amount of oxidized lead-silver ores above the water-level 25 years ago, embraces two ore-horizons from 10 to 20 ft. thick, separated by from 20 to 50 ft. of limestone, and dipping west 33° beneath the eastern dike of granite, which forms the hanging-wall of the western ore-body, and is, in turn, overlain by a heavy bed of chert. The granite seems to conform with the bedding of the limestone, but the under surface of the granite or hanging-wall of the ore is very plane, more or less coated with garnet, as a rule, and beautifully slickensided. This is, evidently, a fault-plane which has, apparently, cut out the main part of the garnet-zone.

In their southward extension to the next ridge, these ore-bodies leave the granite dike, and are thrown eastward, with the great bed of chert, 500, and possibly nearly 1,000 ft., by a transverse flexure or fault. Beyond this displacement they are continued, still on the east side of the chert, in the similar and parallel ore-bodies of the Smuggler claim. About 300 ft. farther east is the parallel ore-zone, from 10 to 15 ft. thick, of the Texas claim, which has not been identified on the Pride of the West ground. The Texas ore is chiefly blende, with walls of limestone; and the garnet-zone is not prominently developed north of Double Standard gulch; but we have now, in addition to the displaced continuation of the double Pride of the West ore-zone on the Smuggler claim, and still holding the same relation to the great bed of chert, though now widely separated from the granite dike, the parallel ore-zone of the Texas claim.

A series of prospect holes extending from the Smuggler workings shows very clearly that the dual ore-body is here flexed backward, and, pinched and dragged out, trends directly toward the tunnel on the Double Standard claim. In other words, we have here a compensating displacement, the dual ore-body being thrown from the south end of the Pride of the West claim eastward into the Smuggler claim, and then westward into the Double Standard claim, where both members, with their normal characters, have been cut by the Double

Standard tunnel. The fact that the granite dike is not thrown with the chert-bed and ore-zones indicates that the displacements, in this case, antedate the intrusion of the granite; but that there has been some movement, at least, along these breaks subsequently to the formation of the ore is made very clear by certain phenomena brought to light in the Double Standard workings. The tunnel cuts the ore-zones just at the break, where they are regaining the normal north-south strike; and a winze was sunk at this critical point on the eastern zone. That this winze is directly in the crushing and disturbance accompanying the great fault is evident from the highly broken and cavernous condition of the ground. That the movement to which this broken and open structure is due was subsequent to the metamorphism of the limestone and the formation of the ore-bodies is unquestionable, since both are involved in the crush breccia. But that this movement was also accompanied or followed by conditions favorable to ore-deposition is proved by druses of pyrite, sphalerite, quartz, etc.; and especially by the occurrence of a cavity several feet in diameter lined with a reniform layer or crust of native arsenic from one to several inches thick. This occurrence of native arsenic, which has been described by Dr. C. H. Warren,[5] undoubtedly finds its best explanation in thermal waters rising along the fault, that is, in something analogous to fumarole action.

On the ridge which we have now reached, separating Double Standard and Bonanza gulches, a section from east to west across the ore-zones shows: (1) the displaced extension of the ore-zone first recognized on the Texas claim; (2) a strong and typical garnet-zone; (3) the double ore-zone of the Pride of the West, Smuggler and Double Standard claims; (4) the massive chert-formation everywhere overlying the dual ore-zone; (5) an unmeasured thickness of crystalline, gray limestone; (6) the Holland ore-zone, not previously recognized, with its garnet-zone. All of these various horizons are recognizable again south of Bonanza gulch, in the Annie, Mary Jane and other claims; and still farther south on the Empire and Belmont claims, the garnet-zones, if not the ore-zones, appear to gain in strength as we approach the granite.

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[5] *American Journal of Science*, 16, pp. 337–339 (1903).

Are the Quartz-Veins of Silver Peak, Nevada, the Result of Magmatic Segregation?

BY JOHN B HASTINGS, DENVER, COLORADO.

(British Columbia Meeting, July, 1905)

CHIEF among the varied problems facing the mine-manager is that of vein-structure and origin, which is highly important as a guide to successful discovery and development. If metalliferous deposits can be traced to the intrusion of waters along definite lines, then is there something tangible for him to study. But when he is told by a geologist that metalliferous deposits are due to some other cause, like magmatic differentiation, while not perhaps discouraged, he is impressed with a vague sense of new worlds to be conquered.

In 1897, while manager of the War Eagle mine at Rossland, B. C., where, previously, the ore-bodies had not been supposed to occur as veins, I suggested to visiting members of the Canadian Geological Survey that, perhaps, the structure of the pyrrhotite-bodies of that mine, which had been proved to occur along well-defined fractures, might throw some light on the similar deposits of Sudbury, then held to be basic aggregations from the original magma. Later investigation has at least provoked discussion of this last deduction, questioning its correctness and suggesting that, perhaps, the deposits are actual veins.

The following extract from a paper by J. E. Spurr[1] is quoted, because it sets forth Mr. Spurr's theory of the quartz-occurrences of the Silver Peak mines, which will be discussed in this article. It also graphically describes the attendant geological features.

"The Drinkwater group of mines, which is the most important part of the Blair gold properties, and which has produced practically all of the million dollars' worth of ore, as above stated, may be taken as typical of the gold-veins which, though widespread and numerons, show a wonderful similarity of character. On the surface two adjacent veins outcrop, the Crowning Glory and the

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[1] Ore Deposits of Silver Peak Quadrangle, *Bulletin No.* 225, *U. S. Geological Survey* (1904).

Drinkwater, the former the larger, the latter containing the greater quantity of good ore. The quality of the ore still left standing (only the richer portions having been removed for milling) has been more or less carefully determined a number of times. . . . .

"Geologically, the veins of the Blair mine are interesting. Properly speaking, they are hardly veins, but flattened lenses of quartz occurring in a definite zone 100 ft. or more in thickness. The lenses wedge out and disappear both horizontally and vertically, and their place is taken by overlapping lenses. The wall-rock is a schist, derived chiefly from the metamorphism of an original limy shale or limestone. Frequently, also, the wall-rock is a very siliceous granitic rock (alaskite), made up essentially of quartz and feldspar. This alaskite occurs in the schist in lenses similar to the quartz There is, moreover, every transition between the alaskite and the quartz; and the schist has been, so to speak, saturated with this siliceous material, which forms seams and thin lenses in it. The auriferous quartz-lenses in the mine in many places run laterally into quartz-feldspar rock (alaskite). As a rule, the values grow insignificant with the coming-in of the feldspar, but occasionally high values may still be found.

"The general conclusion is, that here a series of fissile shales and thin-bedded limestones has been invaded by a very siliceous granitic intrusion which has metamorphosed the sediments to schists *The quartz has plainly the same origin and nature as the alaskite, both being siliceous phases of a granitic magma* [the italics are mine.—J. B. H.]. The gold in the quartz is usually free, sometimes associated with scattered galena [and pyrite.—J. B. H.]. Greenstone or diorite dikes cut the veins or follow along them, but are of later age. Along the dikes there has been water-circulation, resulting sometimes in impoverishment, sometimes in relative concentration of the original values.

"This zone of veins outcrops for a mile along the mountain side. At one point, some distance below the vein-zone, free gold in fresh alaskite-pegmatite country-rock was found.

"In the main, the other gold-mines or prospects of the district have exactly the same geological relations."

At my first examination of the Blair properties, in December, 1900, having, to guide me, the thorough reports of James D. Hague and George W. Maynard, I spent only one day on the hill; at my second visit, in May, 1905, I was half a day at the Blair mines, and three days at the adjoining Valcalde group.

The mines are on ridges north from the Silver Peak, not on that mountain proper, which rises 1,500 ft. higher (to 9,000 feet). It is volcanic; the various flows extend for miles easterly, and the successive stages of its growth are marked. It is reported that there is on the top an oblong depression, 2,000 ft. long, filled with water from melting snow.

Many mining engineers, who have examined veins in schists, will recognize the accuracy of Mr. Spurr's description of the formation in lenses, the disappearance both horizontally and vertically, and the replacement by overlapping ones. They also have sampled veins in granite which have passed gradually

from quartz to granite, and have noted the usual disappearance of metallic values with the appearance of the feldspars.

At my first visit, having no idea of the quartz ever being considered a phase of the granite, and at my last, being busily engaged with the economic features of the Valcalde group, I did not closely study the occurrence of alaskite within the granitic area; but it was seen in proximity to the great cuts on the Drinkwater mine, especially on the northeasterly or hanging-wall; and large masses in front of the vein presented a gneissoid appearance and were extremely silicified. In the southwesterly or foot-wall of the veins, the rock appeared to be normal granite, with muscovite and biotite; occasionally it looked as if the muscovite might be an alteration-product, but usually the rock was in normal condition, except that, in all the pieces found, the biotites were in the last stages of alteration. Alaskite was observed in other places among the mines, and away from the veins; and it seemed as if the absencé of the micas was due, in part, to their elimination near the veins and other zones of movement, and sometimes to differentiation of the magma. The lenses in the schists are usually alaskite; but, as most of these areas have been subjected to solfatarism, I could not decide whether the absence of the mica was primary or secondary. At the Drinkwater group the outer area, bordering the limy shales, is alaskite, and at the Valcalde group the granite adjoins the same rocks. The whole granitic mass of the mines is one magma. There has been fissuring of the normal granite, attended with injection of dikes and formation of veins, but sometimes without either. The micas adjacent to the movement have been more or less destroyed (as in the Boise basin) and aplite has been formed; and again aplite occurs as a phase of the original magma.

Much of the granitic area is slightly fractured, the cracks cemented with the usual quartz as seen in granite, sometimes auriferous, usually not. These quartz seams are white and solid, glassy, chalcedonic or crystalline, and contain cavities, which are sometimes filled in with chalcedonic quartz.

Mr. Spurr speaks of finding gold in fresh alaskite-pegmatite country-rock below the veins. I found coarse gold at a point in the gulch below the Frank No. 2 mine, possibly on the Columbus, and south of the New York, from 200 to 500 ft. from

the veins. The gulch follows a line of movement occupied more or less by a greenstone dike, from 6 to 8 in. wide, dipping flatly to the west. At this particular place the dike is not seen. Along the denuded foot-wall the alaskite is unaltered, except for small deposits of quartz and iron in masses an inch or so in diameter where the gold occurred, and which I take to have been connected with a small quartz-vein 6 in. or less wide, intermittently accompanying the dike, which is also the foot-wall. This vein outcrops at the bottom of the gulch, and the quartz is clearly different from the component quartz of the alaskite. Its strike is NE. and dip NW.; the Blair veins strike NW. and dip NE.; and the Valcalde veins in this neighborhood strike north and dip east.

The following characteristics of the Blair veins were noted: Beginning at the workings farthest south, a 50-ft. tunnel is run in the foot-wall, and two cross-cuts made to the vein; the first one is 20 ft. in the solid white vein-quartz, and not through it; the quartz comes in on well-defined fissuring, course N. 30° W., with regular dip 20° NE. The second cross-cut just enters, at the roof, the same white quartz; there is strong fissuring on the contact; the course is more westerly and the dip is the same as in No. 1. The foot-wall is alaskite, containing a few quartz seams; the vein, as specified, is hard white quartz, separated from the foot-wall by uniform and distinct fissuring. The workings on the south side of the gulch expose the vein with the same quartz and the same flat dip, which follows a well-defined fissuring of the alaskite, and a thin greenstone dike, also fissured. A projected cross-section, showing the uniform dip of the Crowning Glory and Drinkwater veins for 1,000 ft. in depth, is given in Fig. 1.

The main Blair deposits, as Mr. Spurr says, occur in two separate veins; and it may be added that these are parallel and 100 ft. apart.

This outcrop of sheared country-rock and quartz, from 75 to 100 ft. wide, striking about N. 35° W., and dipping from 15° to 50° NE., can be traced for 6,000 ft. across a deep gulch, from the Crowning Glory to the New York. Throughout the whole distance, it is attended with fissuring. At the New York there is a belt of the limey shale, with possibly a fissured dike which the vein follows, being always parallel to the fissur-

ing. The quartz outcrop is very prominent for 500 ft. over the New York hill, and extends some distance beyond. The belt of foreign rock (limey shale, etc.), included in the granite, is about 100 ft. wide, but is local; another inclusion joins it on the north, more evidently the limey shale country-rock; here, both the shale and granite are sheared, but more nearly north and south than at the vein, and with some silicification. Alongside the vein the granite is not sheared on the New York (as it is further south),—as if there had been enough of the shale to take up the movement.

There are, perhaps, three ages of greenstone dikes,—a diorite quite recent, running NW–SE.; a greenstone later than the

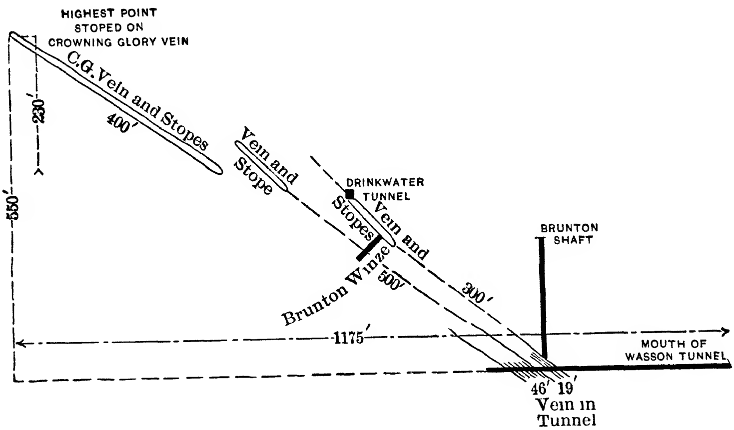

FIG. 1.—PROJECTED CROSS-SECTION OF CROWNING GLORY AND DRINKWATER VEINS

veins and sometimes faulting them, and a greenstone older than the veins, which, to a great extent, the latter have followed.

Mr. Spurr thinks that all the dikes are later than the veins; but those followed by the veins sometimes enclose them, and the quartz is not sheared or broken, while the dike, especially that portion occupied by the vein, is sheared to schistosity. The quartz, both in the dikes and granite, is usually remarkably clean. Distinct silicification of the dikes is seen, which, however, might be secondary.

The Sentinel mine is on the divide between the New York and the Drinkwater, in the limey shale. The only ore-body and occurrence of quartz of consequence is at the open cut alongside

the road. This lens is about 30 ft. long, 20 ft. at the widest, strikes N. 20° W., and dips from 20° to 25° E., conformably with the schists. It is near the granite contact. The fissuring differs from that of the Blair mines, and agrees with the regular foliation of the limey shales; it continues down hill to the north, and is accentuated by lenticular streaks of alaskite intrusions. There has evidently been solfataric action along it, resulting in alteration on a small scale of the schists, and sometimes of the alaskite, and the formation of compact, crystalline and chalcedonic seams of quartz. On the whole, the silicification seems to have affected the schists more than the alaskite.

The Valcalde group, adjoining the Blair, exhibits much narrower veins. It comprises in one vein-system the Columbus, Lincoln, Frank No. 2, Washington and Porto, to which might be added the Lucky Sam, owned by other parties. It seems as if all these claims were on one vein. At least, their characteristics are so uniform, and the portions developed occupy such relative positions, that they may be considered as belonging together. The vein-fissuring and deposition of quartz has followed a pre-existing flat dike, sometimes horizontal, and again dipping as much as 15° easterly or westerly; the dike as seen is from a few inches to 5 ft. thick, and the quartz from a few inches to 6 feet. The dike is distinctly sheared, as is also the granite near the contact, and, in some places, for a foot or two away, the quartz is not broken in the least. The quartz, which is sometimes lenticular in the sheared dike, also occurs in continuous streaks several feet wide within the dike, and also on top of it, with the granite for a distinct hanging-wall. In some places the dike is not seen at all, the quartz occurring as a regular streak in the granite, from 4 to 6 ft. wide, with a remarkably smooth and well-defined hanging-wall. The foot-wall is not exposed.

This flat fissure, extending from the New York 2,000 ft. southerly, outcrops along both sides of a north-and-south gulch (the central portion having been eroded away), and terminates, so far as known, in the basin at the head of it. Laterally, it may be 1,500 ft. wide; this width is only indicated by the Porto mine. It has been disturbed by north-and-south movements, with and without dikes.

The area is either granite or alaskite, the latter in small

patches. The quartz is entirely similar to that of the Blair mines, carrying a little galena and iron sulphides in the best ore.

The Soda mine lies south of the flat vein above described. The vein strikes north and dips 50° westerly. The hard, white vein-quartz is similar to that of the other mines, the best containing galena and pyrite. At the working farthest south, it is found on the hanging-wall of a lenticular mass of an alaskite dike in limey shale. About 30 in. of the alaskite has been silicified. The east or hanging-wall of the quartz is limey shale and a greenstone dike, the relations of which could not be ascertained. The wall is fissured parallel to the vein. The foot-wall is alaskite; and the quartz merges into it. The alaskite lens, as developed, is 25 ft. long, 10 ft. wide at the middle, and of unknown extent, the northern half only being exposed. Beyond this northern half no more alaskite is found; but the vein, composed of quartz stringers and lenses parallel to the foliation of the schists, has been developed, with a width of from 6 to 10 ft., for 300 ft. further.

The Salisbury mine is in granite, a quarter of a mile from the end of the flat vein. It strikes N. 18° E. and dips 55° easterly. The foot-wall is well defined by 2 ft. of strong fissuring, with a small dike. The vein is 40 in. wide, and merges into the granite, having no defined hanging-wall; but the width of the vein, developed for 55 feet, is uniform. It is cut off on the strike by a NW. fault and dike, dipping northeasterly, which carries quartz without values, as the result of a secondary silicification. The vein-quartz is, like that of the other mines, hard and white, and carrying galena and pyrite.

The Paris mine has about the same character as the Soda, but without an alaskite dike; the enclosing walls are schists, within a granite area; the veins are lenticular and small, from 2 to 4 ft. wide, and contain the same white quartz, with galena and pyrite in the best ore. The course is north and south, and the dip 35° east.

A few specimens from the Valcalde group exhibited: (1) wire gold in soft crystalline quartz (called "decomposed" by the miners); (2) crystalline gold in a dog-tooth quartz-lining of a cavity, which was afterwards filled with chalcedony; (3) sheets of gold from cracks in chalcedony; and (4) particles of

gold in the ordinary vein-quartz, that has been freed by oxidation of the sulphides.

From the above it appears to me: (1) That this district presents bodies of quartz of uniform type, following a well-defined fracture-zone with regular course and dip, each great fissure having its own direction, varying from NW. in the Blair mines to N. 18° E. in the Salisbury mine, and a dip from horizontal to 15° westerly and 55° easterly, the easterly dip prevailing.

(2) That the values are in the quartz, which is confined to narrow lateral limits, having well-defined walls, which may be granite, schist, or, in a subsidiary way, greenstone dikes. The passage of the quartz into the granite occurs in the usual manner of veins in a granitoid rock; and the relative amount of accompanying silicified or mineralized granite is not more than usual.

(3) That, consequently, the veins are not siliceous segregations from the granite, but have been formed in the usual manner by ascending waters along lines of fracturing.

The Importance of Fine-Grinding in the Cyanide-Treatment of Gold- and Silver-Ores.

BY FREDERICK C BROWN, MANAGER KOMATA REEFS G. M. CO , LTD , AUCKLAND, NEW ZEALAND

(British Columbia Meeting, July, 1905)

THE practice of fine-grinding is now being so successfully carried on in some fields, notably in West Australia, and its advisability has been so frequently pointed out,[1] that the matter in this paper is not put forward as new; its chief object being to call attention to the importance of fine-grinding in the treatment of comparatively low-grade ores.

I have been engaged during the last five years in the cyanide-treatment of ores in the Ohinemuri district (North Island), New Zealand, and I consider that, in the near future, extremely fine-grinding (almost sliming) will become a very im-

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[1] Bosqui, F. J., A Proposed Filter-Press Slimes-Plant, *Trans*, xxxiv., 715; Christy, S. B., The Cyaniding of Gold-Bearing Sulphurets, *California Miners' Association*, p. 103 (1903).

portant feature of the milling-methods in this field, since it seems absolutely necessary to reduce the most of ores to a very fine state of division if a high extraction is to be obtained; and, in most cases, the extra percentage of saving will leave a good margin above the increased cost of treatment due both to the fine-grinding and to the interest on the capital spent for the grinding-machinery.

The average ore of the Ohinemuri field is composed of a quartz-gangue with some calcite, carrying the gold in the form of an alloy of gold and silver of about equal values, and the silver in the form of mixed sulphides of silver, usually associated with a considerable amount of iron pyrites.

In the upper levels, the ores are decomposed, and carry large quantities of black manganese oxide and some iron oxide; but, as depth is reached, the decomposed ore gives place to sulphides. In some mines, rhodonite, manganese silicate, is present in fairly large quantities. The average value of the ore, received at the mills, ranges from £2 ($10) to £3 ($15) per long ton, the proportion, by weight, of silver to gold being from 8 to 10 of silver to one of gold.

The usual milling-practice is,—1, fairly fine-crushing in stamp-batteries, using wire screens that range from 30 to 40 holes to the linear inch; 2, amalgamation over copper-plates; 3, separation of the slimes from the sands by hydraulic classification; 4, concentration of the sands by means of rubber-belt vanners or Wilfley tables; 5, cyaniding the sands by the percolation-method (in some mills a double treatment is adopted); and 6, cyaniding the slimes by agitation combined with filter-pressing.

In general practice, from 10 to 60 per cent. are saved by amalgamation, and some ores yield a fair percentage of their value by concentration; but in every case the treatment of the sands and slimes by cyaniding is of the utmost importance, because this process is the final one to which the ore is subjected, and any values remaining in the tailings are consequently lost.

My experience has shown that the average loss of undissolved gold and silver in the slimes is small; but in some mills using the decantation-process, a very considerable loss takes place in the final solution carried away with the slimes which are discharged after the treatment. This loss in the slimes

could be obviated by the use of a filter-press, but the necessary plant is very expensive to install, and, unless a mine has assured large ore-reserves, it is sometimes risky to expend the capital. The "Moore" vacuum-process of filtration is now giving encouraging results in the Ohinemuri district, and since the cost of installation of the plant is not excessive, the process might play an important part in the treatment of slimes. A weak feature of the Moore process, however, seems to be that the highest pressure that can be used is comparatively low, say from 11 to 13 lb. to the square inch, which means that a thin cake will be formed in the treatment of very clayey slimes. To overcome this objection a large filtering-area is used which makes the plant somewhat cumbersome. A cheap and efficient system of filtration is greatly needed, and it is quite likely, that, before long, satisfactory results will be forthcoming from the many investigators now working on this problem.

The loss of gold and silver in the sands that are invariably treated by the percolation-method is very considerable. The value of the tailings discharged by the different mills range from 5s. to 10s. ($1.25 to $2.50) per long ton, the proportion of gold being 3s. 9d. to 8s. (95c. to $2) and of silver 1s. 3d. to 2s. (30c. to 50c.). There are two chief reasons to account for these losses:—first, the particles of sand are too coarse to admit of the cyanide solution attacking the enclosed metal; and second, the incomplete treatment and washing received in the percolation-method. The following grading-tests will show how the coarse particles retain the values. The samples, shown in Table I., were taken from the sand-vats after treatment at the Komata Reefs mine:

TABLE I.—*Values of Classified Sands Taken from Vats After Treatment.*

Size of Grain	From One Vat	Average of Five Vats
Remaining		
On 40-mesh	30s ($7.50)	15s 7d. ($3 85)
On 60-mesh.	19s 6d ($4 80)	15s ($3 75)
On 80-mesh	8s ($2 00)	7s. 9d. ($1.90)
On 100-mesh	3s. 4d. (80c)	5s. 4d. ($1 35)
On 150 mesh	....	4s ($1 00)
On 200-mesh	....	2s 6d (60c.)
Through 200-mesh.....	....	2s. 6d. (60c.)

A sample of this ore, crushed and passed through a 35-mesh wire screen, was of the following mechanical composition:

On ..	40-Mesh	60-Mesh	100-Mesh	150-Mesh	200-Mesh	Through 200-Mesh
	Per Cent 3.0	Per Cent 10.6	Per Cent 21 5	Per Cent 11.9	Per Cent 9.3,	Per Cent 43.7

An average sample taken from several miles of the bed of a river into which some of the large mills discharge their tailings had a value, before re-treatment, of 20s. 6d. ($4.95) per ton; its mechanical composition being:

On	30-Mesh.	60-Mesh	90-Mesh	100-Mesh	150-Mesh.	Through 150-Mesh
	Per Cent 1 6	Per Cent 20 0	Per Cent 36 2	Per Cent 21.4	Per Cent 5.4	Per Cent 7 4

The sand was ground in the laboratory so that 74.6 per cent. passed a 200-mesh screen and was then carefully treated with cyanide solution of 0.35 per cent. of KCN. until tests showed that no more gold or silver could be dissolved. The results, determined by assay, showed,—on 200-mesh (24 per cent.), a value of 13s. 6d. ($3.75); through 200-mesh (74.6 per cent.), a value of 4s. ($1.00) per long ton.

During the early days of cyaniding at Ohinemuri, when the surface-ores were being treated, a very fair extraction could be obtained by comparatively coarse crushing (from 30- to 40-mesh in the battery); but as the mines deepen, the quartz becomes harder and denser, and seems to require exceedingly fine crushing in order to liberate the gold and silver, so that the cyanide solutions will attack them.

It is well known to many, that losses occur by the percolation-method of treating sands by the cyanide-process, as is clearly shown by the adoption in some mills of a "double treatment" method, by which a charge is first treated (obviously incompletely) in one vat, and then discharged into another vat and re-treated by the identical process to which it was subjected in the first vat. If the second treatment gives an extra extraction, it can be inferred that three, or even more, treatments would increase the yield. I have taken dozens of samples of sands discharged into the river from some of the large mills of the district which, by re-treatment with cyanide solution, without

re-grinding, have invariably given an extraction varying from 30 to 50 per cent.

After making a large number of experiments, both in the laboratory and on a working-scale, I am of opinion that ores of the value and class above described should be treated in the following manner:—

1. *Grinding.*—Exceedingly fine-grinding, so that about 90 per cent. will pass a 200-mesh screen; this grinding to be followed by amalgamation, if necessary.

2. *Agitation.*—Agitation of the resultant pulp with comparatively weak cyanide solutions accompanied by a large and continuous supply of air during the agitation until the dissolution of the gold and silver, which have been liberated by the fine-grinding, is complete.

3. *Separation.*—Separation and clarification of the gold-bearing solutions by decantation or filtration, or by a combination of both methods.

4. *Precipitation.*—Precipitation of gold and silver from the solutions by zinc-shavings, zinc-dust or other suitable method.

1. *Grinding.*—The fine-grinding can be accomplished economically in what are known as tube-mills, which are simply lined wrought-steel cylinders about 4 ft. in diameter, and from 16 to 20 ft. long, supported on end-trunnion bearings, and half filled with rounded flint pebbles about the size of a hen's egg. These machines are run at a speed ranging from 32 to 27 rev. per min., and the crushed ore from the battery, after the separation of the slimes, is fed in at one end of the machine and discharged at the other end into a hydraulic classifier. From the classifier, that portion of the pulp which is fine enough, overflows and goes to the treatment-plant, the coarse particles being discharged at the bottom of the classifier into an elevator, and returned to the feed-end of the tube-mill for re-grinding. These machines have long since passed the experimental stage, and are used advantageously in West Australia; they are also being installed at several mills in South Africa, Mexico and New Zealand.

2. *Agitation.*—The agitation of large quantities of very fine sand, under conditions suitable for economical and efficient treatment, has, until now, not been by any means a simple matter; but I have recently perfected an apparatus which fills

the following necessary requirements—low cost of installation; no wearing parts; simple and easy in operation; and perfect agitation and aëration of the charge.

The apparatus consists of a tall vat of comparatively small diameter having a cone-shaped bottom, in the center of which is fitted an air-lift pump, the cone being fitted with an arrangement of jets for "softening" the charge at the commencement of the agitation. The sand and solution at the bottom of the tank are continuously lifted and discharged at the top of the tank, and as such fine material has not a great tendency to settle, this circulating-action can be carried on indefinitely with the expenditure of very little power. The conditions for cyanide treatment are perfect, since every particle of sand and slime is constantly coming into contact with the solution and air as it enters the bottom of the air-lift column. Tanks large enough to treat charges of 50 tons are now in successful operation, and larger ones can be built to handle 100 tons or more at a charge.

3. *Separation.*—The separation of the gold-bearing solution from the pulp can be accomplished by natural settlement and decantation, but this method, especially with some ores, is very slow and requires a large plant; hence, in the case of a mine with a fair length of life before it, some sort of filtration-plant should be used. If circulating-vats, as described above under "agitation," be employed, a combination of natural settlement and filtration could be adopted, since very fine sand settles fairly rapidly after agitation in tall vats, and a large percentage of the slimes is carried down with the sand. Therefore, if, after each agitation, a comparatively short time be allowed for settlement, the supernatent solution, together with the slimes, can be decanted off and passed through a filter-press. By this arrangement a very small filter-press plant would be required, and, as the washing of a charge in these vats is simple, a very high percentage of the gold-bearing solution can be recovered at a small cost.

The advantages arising from the system of very fine-grinding outlined above, compared with coarser crushing, are threefold, viz.:—

The dissolving of the gold and silver in the ore takes less time; weaker cyanide solutions can be used; and a better extraction can be obtained.

Treatment of Concentrates.

Concentration has not been included after the grinding treatment, but it is quite likely to be used in those special cases, where an ore carries minerals which cannot be successfully treated by the cyanide process, and the elimination of which is necessary to the successful subsequent treatment of the tailings. With ores, however, that yield concentrates which can be successfully treated by the cyanide process (provided they are very finely ground, sometimes even "slimed"), it is probable that the suggested very fine-grinding would reduce the mineral particles of the ore, which are considerably softer than the sand particles, to such a fine state that their values would be extracted by the agitation-system above described. As a result of many experiments in treating concentrates by the cyanide process, I have found that the chief points to be observed are:—

1. The concentrates must not be allowed to become decomposed by being left exposed to the air.

2. Exceedingly fine-grinding is necessary in most cases, and usually the concentrates must be reduced to slimes.

3. Agitation must provide a good supply of air.

4. Weak cyanide solution will give a good extraction, provided the grinding is fine enough. Since all the above conditions would be obtained by treating the mineral particles, viz., the concentrates, together with the sand, it would seem as if the special operation of concentration could be dispensed with in some cases, which would mean a great saving in the cost of plant and in its operating expenses.

The Manufacture of Coke in Northern China.

BY YANG TSANG WOO, TONG SHAN, CHINA.

(Washington Meeting, February, 1905.)

THE method of making coke that has been adopted at the Kaiping and other collieries in northern China resembles, to some extent, the familiar bee-hive oven process of the United States, except that a kiln with permanent sides is used instead of a closed oven, and the products of combustion are drawn off at the bottom.

In building coke-kilns in China, two circular holes, 8 ft. 6 in. in diameter at the bottom and 13 ft. in diameter at the top, are excavated in the ground, and connected at the bottom by a flue, as shown in Figs. 1 and 2. The sides and bottom of the kiln are lined with fire-bricks, and covered with a layer of fire-clay, and a rectangular opening, 6 in. by 8 in., connects the bottom of each kiln with the main flue. Around the edge of the hole, and overlapping the lining, is a wall of fire-brick extending 2 ft. 6 in. above the level of the ground. An open space 5 ft. wide is left in this wall, through which the coal is carried into the kiln and the resultant coke removed. This space, of course, is bricked up during the time that the coking-operation is being carried on. The wall is pierced with nine flue-openings uniformly placed around the circumference, each intervening space in the wall being strengthened with a brick buttress, as is shown in Figs. 2 and 4. The floor of the kiln, as well as the main flue, is lined with fire-brick.

Before charging the coal, it is first placed in shallow bamboo sieves, 2 ft. in diameter, and immersed in a trough 10 ft. long, and 3 ft. wide, fed with pit-water, in which it is washed by hand. Fig. 3 shows the manner in which the washing is done. From 25 tons of good "dust" coal, 22.5 tons of washed coal are obtained.

When ready to charge the coal into the kiln, a temporary cone-shaped flue of fire-wood and lump coal is first built to a

height of 2 ft., directly above the rectangular opening in the bottom of the kiln; washed coal is then filled in to the level of the top of this flue, and stamped compactly in place by coolies wearing flat wooden-soled shoes. Then from the top of this flue nine temporary rectangular flues are made of broken fire-brick radiating from the center to the flue-openings in the wall. These flues have an interior cross-section 2 in. square at the center of the kiln, increasing to 7 in. square at the wall, and slope gradually upward toward the wall. On top of the stamped coal a flue 6 in. high is formed of coke, in order that air may reach the coal in the upper part of the kiln. The remainder of the charge of coal is then piled over the flues to a height of 6 ft., the top being rounded off as shown in Figs. 1 and 3.

After the fire has been started, and the operation of coking is well under way, any flame or gas escaping through the top of the coal in the kiln shows that the coal directly underneath the place of escape has been coked; and in order to prevent access of air which would burn this coke, a layer of earth is spread over such places. After all the gases have escaped, water is poured on the top to extinguish the fire and cool the coke. About two weeks are required for coking, and two days for cooling a charge. Each charge of 22.5 tons of washed coal yields 10 tons of good coke and 1 ton of ashes. The price of good "dust" coal at the pit-mouth is $4.50 (Mex.) per ton, and, as the coke sells at from $18 to $20 per ton, according to quality, the profit is considerable.

Analyses of coke made at the collieries of the Chinese Mining and Engineering Co., Tong Shan, North China, are:—carbon (by difference), 83.276; hydrocarbons, 0.06; sulphur, 0.969; moisture, 0.48; ash, 15.215; total, 100 per cent.

The washing of the coal, the filling and the discharging of the ovens, and the coking-operations are done by contract which costs $6.50 (Mex.) per oven. Each contract-laborer earns about 20c. (Mex.) per day.

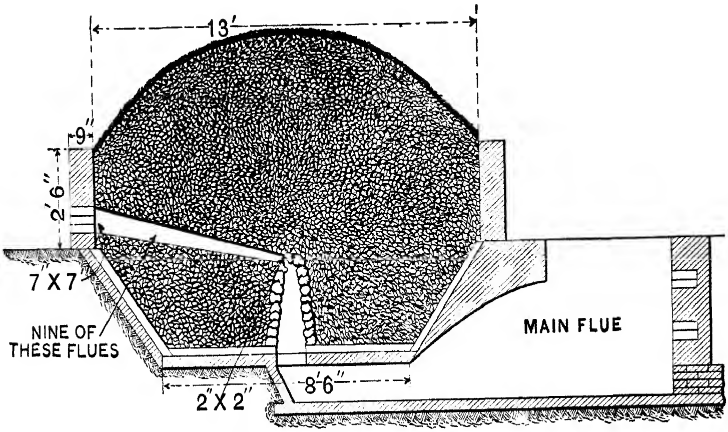

FIG. 1.—TRANSVERSE SECTION.

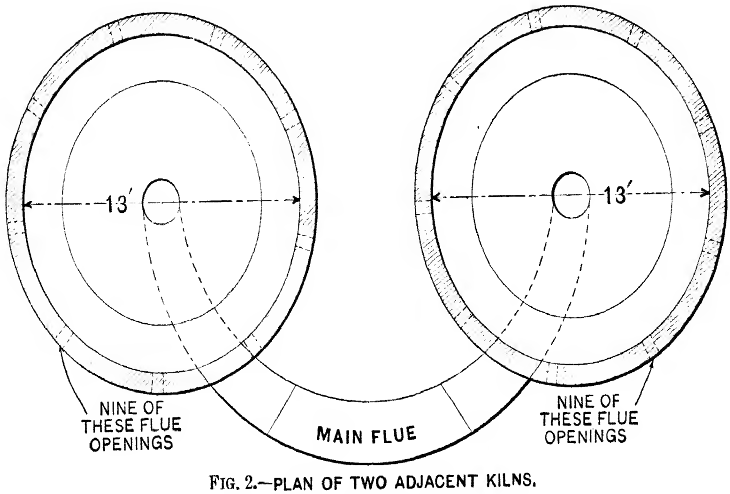

FIG. 2.—PLAN OF TWO ADJACENT KILNS.

COKE-KILNS AT KAIPING, CHINA.

FIG. 3.—Washing Coal in Troughs.

FIG. 4.—Charging Coal into Kilns.
COKE-KILNS AT KAIPING, CHINA.

The Constitution of Mattes Produced in Copper-Smelting.

BY ALLAN GIBB AND R. C. PHILP, MT PERRY, QUEENSLAND, AUSTRALIA.

(Lake Superior Meeting, September, 1904)

I. Introduction.

The term "matte" is applied to smelting-products so extremely diverse in composition and physical properties that it appears impossible to devise any generic formula to represent, chemically, the manner in which the varied proportions of the almost unlimited possible constituents combine with each other.

Mattes produced in copper-smelting, in distinction from those produced in smelting-operations in which the recovery of copper is secondary to that of other metals, cover a narrower range in composition. The copper-content of such mattes vary from 20 to 80 per cent., and even this range is much smaller in general practice since it is found advantageous, when possible, to produce mattes with about 50 per cent. of copper in the first operation. Further, it is unusual that arsenic or antimony occurs in copper-ores in sufficient proportions to form arsenides or antimonides in such quantities that they will separate out from the furnace-products, as is common in lead-smelting. Generally, the mattes produced in copper-smelting are composed mainly of copper (usually greater than 35 per cent.), iron and sulphur, the remaining elements being usually in proportions sufficiently small to allow of their treatment as impurities, rather than as essential constituents of the mattes.

In modern practice of smelting copper-ores in blast-furnaces the tendency is to approach pyritic smelting as nearly as possible, the furnaces being low and the air supplied being largely in excess of that required for complete combustion of the carbonaceous fuel. Hence, the atmosphere of the blast-furnace thus used is usually oxidizing or nearly neutral, and, as a consequence, the reduction of metallic iron that was a necessary evil of former practice is of unusual occurrence in operations where the main object is the recovery of copper. Hearth-accre-

tions of metallic iron are uncommon, and that metal does not enter into the composition of mattes to the extent that was formerly the case.

Having had occasion to smelt copper-ores composed entirely of copper, iron and sulphur, and free from the impurities usually present, we have examined the resultant mattes with a view to forming a basis for the study of the constitution of the mattes produced in smelting ordinary copper-ores.

Mattes produced in copper-smelting receive technical names more or less indicative of their general appearance. The matte produced in smelting ores usually contains from 35 to 55 per cent. of copper, and is known as "coarse metal." This material is hard, compact, of dull-bronze color and contains no visible metallic copper. When the proportion of copper exceeds 60 per cent. the color of the matte becomes a bluish-purple, and filaments of metallic copper (moss-copper) separate out in considerable quantity. Such matte is known as "blue metal," and retains its characteristics until the proportion of copper approaches 70 per cent. Matte containing from 70 to 76 per cent of copper has a white, unevenly-plated appearance, and is called "white metal," and, though generally of very homogeneous appearance, it frequently contains metallic copper that is visibl to the naked eye. When mattes are more highly concentrated metallic copper separates out in considerable proportion an the accompanying mattes, with from 78 to 81 per cent. of copper, receive various names, "pimple metal," "close regule, "spongy regule," etc., according to their appearance.

II. Line of Research.

The object of this research being the study, both from chemical and a physical standpoint, of the constitution mattes produced in copper-smelting, the investigation involve synthesis and analysis. Synthetic mixtures of copper, iron an sulphur, and their compounds, were subjected to temperatur similar to those of the smelting-operations, and the constitutic of the products investigated; the products of the smeltin operations also were examined.

With a view to determine the chemical combinations which copper, iron and sulphur occur in mattes, we have e amined the action of neutral solutions of silver nitrate up

the various compounds and mixtures of these elements and their compounds, and this reagent has proved invaluable in the general investigation. The following is a summary of our conclusions:

1. Cuprous sulphide (Cu_2S) is rapidly and completely decomposed according to the following equation.

$$Cu_2S + 4\ AgNO_3 = 2\ Cu(NO_3)_2 + Ag_2S + 2\ Ag.$$

2. Metallic copper readily precipitates metallic silver in equivalent proportions.

$$Cu + 2\ AgNO_3 = Cu(NO_3)_2 + 2\ Ag.$$

3. Cuprous oxide (Cu_2O) precipitates metallic silver and forms a basic nitrate that is insoluble in the reagent.

$$3\ Cu_2O + 6\ AgNO_3 + 3\ H_2O = 6\ Ag + 2\ Cu(NO_3)_2 + 2\ Cu_2O, OH, NO_3, H_2O.$$

4. Ferrous sulphide (FeS) is inert.

5. Metallic iron slowly precipitates metallic silver, but great length of time is necessary to complete the reaction.

6. All of the foregoing conclusions apply to the complex mixtures and compounds, produced by fusion of cuprous sulphide, ferrous sulphide, cuprous oxide, metallic iron and metallic copper.

III. Copper, Iron and Sulphur Compounds, Stable at Fusion-Temperatures.

Copper and Sulphur Compounds.—1. Cuprous sulphide (Cu_2S), fused with sulphur in a closed crucible, after cooling, was crushed and fused again with sulphur. The product, allowed to cool in the crucible, was found to be unaltered in composition.

2. Cuprous sulphide, fused with metallic copper, was left in the furnace for some time at a high temperature. A button of metallic copper and a regulus identical in composition with the original cuprous sulphide were obtained.

3. Cupric sulphide (CuS) was fused alone, and respectively with metallic copper and with sulphur. In every case the product was cuprous sulphide (Cu_2S). Hence it is apparent that the

only compound of copper and sulphur that can exist in a fused state is cuprous sulphide; also that cuprous sulphide will not dissolve an excess of either of its constituents.

Iron and Sulphur Compounds—1. Commercial ferrous sulphide was fused twice with sulphur, the product in each case being allowed to solidify in the crucible. The final product contained 63.52 per cent. of iron, being practically pure ferrous sulphide.

2. Commercial ferrous sulphide was fused with a large excess of iron filings. A button of brittle iron was obtained with a regulus that contained 87.6 per cent. of iron. This was the highest proportion of iron that could be introduced into the product, though all proportions between 87.6 and 63.5 per cent. were possible. The regulus was brittle and contained no visible metallic fragments. This regulus was digested for several days in neutral silver nitrate which dissolved 20 per cent. of the iron, but no attempt was made to obtain complete solution of the iron.

One gram of this regulus was treated with dilute hydrochloric acid in an apparatus arranged to allow of the absorption of the hydrogen sulphide and the subsequent collection of hydrogen. Two experiments, in which only rough corrections were made for temperature and pressure, gave a mean of 248 cc. of hydrogen evolved. Assuming that the whole of the iron in the regulus beyond that required to form ferrous sulphide was metallic iron, and that it would dissolve in acid and form hydrogen, the quantity of gas evolved at normal temperature and pressure would have been 252 cc., a figure sufficiently close to the experimental results to show that the regulus consisted of a solid solution of metallic iron in ferrous sulphide.

These results show that compounds of iron and sulphur with higher proportions of sulphur than that contained in ferrous sulphide cannot be formed by fusion, but that the proportion of sulphur may be considerably reduced, the minimum being probably reached at about 13 per cent. The lower proportions of sulphur are, however, the result of solution of metallic iron in ferrous sulphide, rather than the formation of chemical compounds with greater proportions of iron than in ferrous sulphide.

Finally, ferrous sulphide appears to be the only compound of the two elements possible in materials that have been subjected to fusion.

Cuprous Sulphide and Metallic Iron.—Cuprous sulphide was fused in a crucible, and rods of iron introduced into the molten material of sufficient thickness to insure that they would not melt during the time the crucible was in the furnace. A button of metallic copper was obtained and a regulus containing:—copper, 60.6; iron, 17.8; and sulphur, 21.6 per cent.

This regulus was decomposed by neutral silver nitrate, and was found to contain cuprous sulphide, 56.3; ferrous sulphide, 28.0; and metallic copper, 15.7 per cent.

Metallic iron decomposes cuprous sulphide according to the equation;—

$$Cu_2S + Fe = FeS + 2Cu,$$

and the ferrous sulphide, so formed, mixes with the cuprous sulphide, and yields, finally, a regulus, containing about 30 per cent. of ferrous sulphide, that is not decomposed by metallic iron.

Ferrous Sulphide and Metallic Copper.—Ferrous sulphide, prepared by precipitation, was fused with a large excess of metallic copper, yielding a button of copper and a regulus composed of iron, 25.0; sulphur, 14.3; and copper, 60.7 per cent.

Ferrous sulphide dissolves metallic copper in all proportions up to 120 per cent. of its weight.

This action was one of solution and not of decomposition, as was shown on attacking the regulus with a solution of silver nitrate. The quantity of precipitated silver amounted to 208 per cent. of the regulus treated, and was equivalent to the metallic copper.

Double Sulphides of Copper and Iron.—Solutions of cupric and ferrous sulphates were mixed in varying proportions, and the metals precipitated therefrom as sulphides. After washing the precipitates, they were fused under a layer of glass in closed crucibles. The products were apparently homogeneous and had the compositions given in Table I.

Cuprous and ferrous sulphides in all proportions may be fused together to form apparently homogeneous products, and

TABLE I.—*Composition and Calculated Constitution of Double Sulphides of Iron and Copper.*

Components.	No. 1.	No 2	No 3	No 4.	No 5	No 6
	Per Cent.	Per Cent	Per Cent.	Per Cent.	Per Cent.	Per Cent
Copper.............	78.5	72.1	63.5	56.2	34.2	23.4
Iron	1.1	6.1	13 0	18.8	36 4	45.6
Sulphur	20.4	21.8	23.5	25.0	29.4	31.0
	100.0	100.0	100.0	100.0	100.0	100 0
Calculated Constitution						
Cuprous sulphide..	98.3	90.4	79 6	70.4	42.8	29.3
Ferrous sulphide	1.7	9.6	20.4	29.6	57.2	70 7

the double sulphides referred to in Table I. were fused with an excess of metallic copper, yielding the results set forth in Table II.

TABLE II.—*Composition and Calculated Constitution of Double Sulphides of Iron and Copper.*

Components	No 1.	No 2	No 3.	No 4	No 5.	No 6
	Per Cent	Per Cent	Per Cent.	Per Cent	Per Cent	Per Cent
Copper	80.4	72.1	63 9	60.7	57.5	57.3
Iron....... ...	1.0	6.1	12 9	16.8	23 5	25 1
Sulphur	18.6	21.8	23.2	22.5	19.0	17.6
Physical characteristics.	Hard, compact. Gray-colored, showing some metallic copper.	White, compact, very homogeneous—typical white metal.	Bluish-white, with many cavities, showing some metallic copper.	Bluish, compact.	Bronze-colored.	Bronze-colored, excess of copper not well separated.
Calculated Constitution						
Cuprous sulphide..	89 2	90 4	78.5	63.7	27.7	16.5
Ferrous sulphide..	1.5	9 6	20.2	26.4	36.9	39.4
Metallic copper...	9.3	....	1.3	9 9	35 4	44 1

Double sulphides of copper and iron, with the exception of No. 2 in Table II., have the property of dissolving metallic copper. The regulus, consisting approximately of 90 per cent. of cuprous sulphide and 10 per cent. of ferrous sulphide, having all the characteristics of white metal, appears to form a divid-

ing line between the double sulphides, in which the excess of copper is held in mechanical suspension, and those in which ferrous sulphide acts as a solvent.

Magnetic Iron Oxide in Mattes.—By dissolving the mattes produced in copper-smelting in nitric acid, an insoluble black powder frequently remains. This powder consists of magnetic iron oxide (ferroso-ferric oxide). A sample of matte made in a reverberatory furnace, from which a considerable proportion of this residue separated on solution, consisted of copper, 54.9; iron, 22.4; and sulphur, 22.7 per cent. There were no impurities present apart from minute proportions of gold and silver.

This matte was finely ground and digested in various solvents, first in the cold and finally at a boiling-temperature. The residues were collected as in gold-parting, and the following data were obtained:

Solvent	Residue Ferroso-Ferric Oxide
	Per Cent
20 cc. nitric acid, 1 g. potassium chlorate...... ..	2.30
20 cc nitric acid, 2 g. potassium chlorate...... ...	2.60
20 cc. nitric acid, 5 g. potassium chlorate	3 63
20 cc. nitric acid	1.86
20 cc dilute nitric acid	1.90
15 cc. nitric acid, 10 cc. sulphuric acid..	nil.

The foregoing determinations show the proportion of the ferroso-ferric residue to be very variable, and, moreover, that the proportion increases with the oxidizing energy of the solvent used. Magnetic iron oxide which is formed at high temperatures is quite insoluble in concentrated sulphuric acid, whereas the residues from the experiments were readily soluble in that reagent. It appears, therefore, that the ferroso-ferric oxide is the result of precipitation by the oxidizing agent, rather than an original constituent of the matte. While the foregoing experiment only indirectly proves the non-existence of ferroso-ferric oxide as a constituent of mattes, subsequent data are given that explain the constitution of mattes without making allowance for this, to say the least, doubtful constituent.

IV. Mattes from Copper-Smelting.

Samples of matte of increasing proportions of copper were obtained, which were composed entirely of copper, iron and

TABLE III.—*Results Obtained by Treating Copper-Mattes with Silver Nitrate.*

Sample	Copper	Iron.	Sulphur.	Residue	Copper in Residue.
	Per Cent.	Per Cent	Per Cent	Per Cent.	Per Cent
No. 1 ..	49.7	27.0	23.3	220	nil.
No. 2...	55.6	21.6	22 8	233	nil
No. 3 ..	61.2	16.4	22 4	247	nil.
No. 4...	66.8	11.4	21.8	260	nil.
No. 5...	70.8	7.6	21 6	271	nil.
No. 6 .	71.7	6 4	21.9	274	nil.
No. 7.	72.1	6.2	21 6	273	0 6
No. 8...	74 8	4.2	21 0	280	0.6
No 9 .	78.0	1.8	20 2	287	0 6
No. 10 .	79.2	1.0	19 8	290	0 8
No. 11 ..	80 1	0.4	19.1	292	1 6

Residues

Sample.	Weight.	From Ferrous Sulphide	From Cuprous Sulphide	From Metallic Copper.	From Cuprous Oxide
		Fe S	$Ag_2S + 2\ Ag$	2 Ag	$6\ Ag + 2\ Cu_2O$, OH, NO_3, H_2O
	Per Cent	Per Cent	Per Cent	Per Cent.	Per Cent
No. 1 .	220.7	42.4	114.4	63.9	nil.
No. 2	234.9	33.9	152 3	48 7	nil.
No. 3 .	248.5	25.8	188 4	34.3	nil.
No. 4 .	261.8	17.9	223.0	20.9	nil.
No. 5..	271.8	11.9	251.0	8 9	nil.
No. 6 .	274 5	10.0	264.5	nil.	nil.
No. 7. .	274.1	9.7	263.0	nil.	1.4
No. 8	280.5	6.6	270 0	2.5	1.4
No 9 .	288.3	2.8	278.0	6.1	1.4
No. 10..	291.1	1.5	278.0	9.5	2.1
No. 11..	293.0	0.6	276 0	11.7	4.7

Calculated Constitution

Sample	Cuprous Sulphide	Ferrous Sulphide	Metallic Copper	Cuprous Oxide
	Per Cent.	Per Cent	Per Cent	Per Cent.
No. 1. . . .	39.0	42.4	18.6	nil
No. 2.	51.9	33.9	14.2	nil.
No. 3.....	64.2	25 8	10.0	nil.
No. 4......	76.0	17.9	6.1	nil.
No. 5	85.5	11.9	2.6	nil.
No. 6	90.0	10 0	nil.	nil.
No. 7......	89.5	9.7	nil.	0.6
No. 8......	92 0	6.6	0.8	0.6
No. 9	94.8	2.8	1.8	0.6
No. 10	94.8	1.5	2.8	0.9
No 11. ..	94.0	0.6	3.4	2.0

sulphur, except for minute proportions of gold and silver. These finely-divided samples were digested in solutions of neu-

tral silver nitrate, and the resulting residues contained:—the whole of the ferrous sulphide; metallic silver and silver sulphide equivalent to the cuprous sulphide; metallic silver equivalent to metallic copper if present; and basic copper nitrate and metallic copper equivalent to any cuprous oxide.

The solutions were examined for iron, but in no instance was it found; hence, none of the samples contained metallic iron, for the reason that this metal, even when dissolved in ferrous sulphide, decomposes silver nitrate, though the action is slow.

The analytical data obtained from these samples of copper-matte are given in Table III.

In order to determine whether the excess of copper was held mechanically, or whether actual solution had taken place, the samples were fused in closed crucibles and the molten mass allowed to solidify in the furnace. Buttons of metallic copper were obtained only from samples Nos. 8, 9, 10 and 11, partly from fusion together of globules, and partly from the reduction of copper by the reaction of copper sulphide and copper oxide, as is shown in Table IV.

TABLE IV.—*Results Obtained, which Yielded Metallic Copper.*

Sample	Metallic Copper Obtained	From Cuprous Oxide	In Original Matte
	Per Cent	Per Cent	Per Cent
No. 8......	1.70	0.80	0.90
No 9..	2 50	0.80	1.70
No. 10 . .	4 00	1 20	2.80
No 11	5.10	2.60	3.50

The data in Table IV. agree with the calculated quantities, and show that the whole of the excess of metallic copper is held in mechanical mixture. Metallic copper was produced by fusing sample No. 7, but the buttons formed were too small to be collected. The excess of metallic copper is evidently held in solution by ferrous sulphide when that compound forms more than 10 per cent. of the matte; whereas, when less than 10 per cent. is present, the metallic copper, if present, is held in mechanical suspension.

We have given the name of white metal to the matte that contains 90 per cent. of cuprous sulphide and 10 per cent. of ferrous sulphide, and we distinguish it from other mattes ap-

proximating this composition, that are, from their physical appearances, generally classed under that name. We have used the name white metal, for lack of a better one, to indicate the matte in which the combination of the metals with sulphur exactly satisfies the chemical requirement. When copper, iron and sulphur constitute the whole matte, it corresponds to the formula 5 Cu_2S, FeS.

Physical Properties.—The samples Nos. 1 to 6, in Table III., were quite homogeneous in appearance, whereas the others contained metallic copper visible to the naked eye. Samples Nos. 3 and 4 were taken from bulks in which a considerable proportion of moss-copper occurred, but it was possible to select matte that was quite free from this material. This was not the case with samples Nos. 7 to 11, in which finely divided metallic copper was intimately mixed.

Microscopic Examination.—Portions of all of the samples were polished and examined under the microscope. The samples were almost identical in appearance, except that samples Nos. 7 to 11 showed metallic copper. The matte portion of the samples was grayish-black in color and of very uniform appearance.

The samples were polished and subsequently attacked by dilute solutions of silver nitrate which gave the following data:—

Sample No. 6 (white metal) was uniformly coated with a dull-gray material which was probably a mixture of metallic silver with sulphides of silver and iron.

Samples Nos. 1 to 5 had a ground-work identical in general appearance with sample No. 6. In this specimen were irregular patches of a dark-gray material containing glistening crystals of metallic silver.

Samples Nos. 7 to 11 were mainly similar to sample No. 6, but contained innumerable glistening facets of metallic silver uniformly distributed over the gray coating.

These observations, we think, show that white metal ($5Cu_2S$, FeS) enters into the composition of samples Nos. 1 to 5. The sample that satisfied this formula was perfectly homogeneous. When ferrous sulphide occurs in mattes in excess of the proportion required for this formula, the excess separates from the white metal on cooling. The excess of ferrous sulphide is the agent that dissolves the metallic copper occurring in these

mattes, as is demonstrated by the precipitation of metallic silver, in crystals of considerable size, upon the dark patches of ferrous sulphide.

The constitution of mattes in which the cuprous sulphide is in excess of that required by the formula for white metal, is not so obvious from the foregoing results. That metallic copper occurs disseminated through the mass, is shown by the formation of innumerable independent crystals of metallic silver. The products obtained by attacking white metal and cuprous sulphide with silver nitrate are, however, so nearly alike, that the attacked surfaces of these mattes present a uniform appearance except for the crystals of metallic silver formed by the metallic copper.

Owing to the unsatisfactory re-solution by silver nitrate of the constituents in samples Nos. 7 to 11, the sections were repolished and etched with potassium cyanide. Upon re-examination it was found that sample No. 6 (white metal) was very uniformly etched, consisting mainly of a light-gray material in the midst of which were innumerable, uniformly distributed, dark-colored, minute particles. Samples Nos. 1 to 5 consisted of a ground-work similar to white metal, in which were light-gray patches markedly isolated from the main body. The proportion of these patches to the whole increased with the proportion of iron in the sample.

In samples Nos. 7 to 11, the uniform structure of sample No. 6 gradually gave place to a material, similar to that of sample No. 6, but with steel-gray patches until, in sample No. 11, the mass was composed almost entirely of this gray material, occasionally having enclosed patches of material similar to sample No. 6. Metallic copper was visible.

These observations fully confirm those made on the samples attacked by silver nitrate. Ferrous sulphide is not acted upon by potassium cyanide; whereas, both metallic copper and cuprous sulphide are attacked. Sample No. 6 is obviously composed of a chemical combination of cuprous sulphide and ferrous sulphide. As was observed, no such uniform and intimate mixture of these two sulphides could be obtained except from the decomposition of a chemical compound. In samples Nos. 1 to 5 the light-gray patches were obviously due to the action of the re-agent on the metallic copper dissolved in ferrous sulphide.

The extraction of this metal from the solid solution left the ferrous sulphide fresh and bright in a way that would be impossible to obtain by mechanical polishing. The ground-work was obviously white metal. In samples Nos. 7 to 11 the gradual decomposition of the white metal was distinctly noticeable, and its replacement by cuprous sulphide was evident by the gradually increasing proportion of steel-gray material which could only be evenly-etched cuprous sulphide.

Pyrometric Measurements.—The following determinations of melting-points were made:

Sample	Copper-Content	Melting-Point
	Per Cent	Degrees C
A.	32.6	875
1.	49.7	955
3	61.2	1,070
6.	71.7	1,121
11.	80 1	1,098
Metallic copper.	100 0	1,083

These temperatures are those at which the main solidification of the melted samples took place. We did not have sensitive recording-apparatus that might have shown the mattes to be made up of two or more components of different melting-points. In the case of sample No. 11 it might have been expected that the copper mechanically held by the matte would have caused a definite arrest in the cooling-curve at 1,083° C., but when this matte is melted, the excess of metallic copper collects at the bottom of the containing-crucible and is out of contact with the pyrometer.

White metal has the highest melting-point of the whole series, and any addition of either component beyond the proportions required to satisfy the formula, 5 Cu_2S, FeS, causes a fall in the melting-point. This fact is additional evidence of the probability that the matte we have called white metal is a chemical compound.

Matte Concentration.—The probable existence of the compound, 5 Cu_2S, FeS, in mattes, puts us in a position to explain the phenomena attending the concentration of mattes in copper-smelting. The analytical data given in Table III. may also be arranged as in Table V.

TABLE V.—*Rearrangement of Data Given in Table III.*

Sample	Ferrous Sulphide	White Metal	Cuprous Sulphide.	Metallic Copper	Cuprous Oxide.
	Per Cent	Per Cent.	Per Cent	Per Cent	Per Cent
No. 1 ..	38 1	43.3	nil.	18 6	nil.
No. 2. .	28 1	57.6	nil	14.2	nil.
No. 3 .	16.7	71.4	nil.	10 0	nil.
No. 4..	9 5	84.5	nil	6 1	nil.
No. 5.	2 4	95.0	nil	2.6	nil.
No. 6...	nil	100 0	nil	nil	nil
No. 7.....	nil.	97 0	2.2	nil.	0 6
No. 8...	nil	66 0	32.6	0.8	0 6
No 9. ..	nil	28 0	69.6	1.8	0.6
No 10...	nil.	15 0	81.3	2.8	0 9
No 11. .	nil.	6 0	88 6	3 4	2.0

The principal chemical reactions that take place in copper-smelting result in the formation of metallic copper, although the presence of sulphides may produce cuprous sulphide from the copper so formed. It has generally been considered that metallic copper, formed prior to the stage at which it collects as a copper-bottom, is only a theoretical conception, the enrichment of mattes being attributed to processes of oxidation. We consider that the foregoing experimental work shows that metallic copper is actually formed at all stages of copper-smelting, and that it exists in the various products, either held in solution by ferrous sulphide or mechanically mixed with the matte.

Samples Nos. 1 to 5 in Table V. show that the ratio of the ferrous sulphide (after eliminating that required to form the compound 5 Cu_2S, FeS) to the metallic copper gradually decreases. In other words, the excess of ferrous sulphide holds a greater proportion of metallic copper. Apparently, under the conditions of copper-smelting, ferrous sulphide becomes supersaturated with metallic copper when it has dissolved 60 per cent. of its weight, and, on cooling, it gives up a portion of the dissolved copper as moss-copper. This is probably the reason why the formation of moss-copper is only observed in mattes containing from 60 to 70 per cent. of copper. It has been shown conclusively that the matte we have called white metal does not dissolve metallic copper, consequently any copper that may be formed at this stage is apparently re-sulphidized. This matte, however, is only a boundary-line, and, when the concentration passes it, we have further evidence that ferrous sulphide in excess of that required to satisfy the

formula 5 Cu_2S, FeS is capable of dissolving metallic copper. When the concentration is carried beyond white metal, the mattes still contain metallic copper; but it is held in mechanical suspension only. The principal action at this stage appears to be the decomposition of the compound 5 Cu_2S, FeS. Metallic copper and cuprous oxide are formed, and are held mechanically by the matte; but it is not until the white metal is practically all decomposed that metallic copper is formed in sufficient quantity to separate from the matte in the form of copper-bottoms.

Impurities in Mattes.—The foregoing conclusions refer to mattes composed entirely of copper, iron and sulphur. This condition is most unusual, copper-ores being generally associated with minerals the constituents of which are reduced with the copper in the ordinary smelting-processes. The elements that may enter into the composition of mattes produced in copper-smelting are innumerable, but so far as this investigation is concerned, they never occur in the proportions common to other smelting-operations.

The proportions of the impurities occurring in mattes produced in copper-smelting are almost invariably sufficiently small to render immaterial the exact state of chemical combination ın which they occur.

Table VI. gives analyses of mattes containing typical proportions of the more common impurities.

TABLE VI.—*Composition of Typical Mattes Containing Impurities.*

Components.	1	2
	Per Cent	Per Cent
Copper...	72.91	54 06
Iron	5.00	22 15
Sulphur	21.15	22 50
Arsenic.....	0.47	0 23
Antimony. .	0.11	0 04
Bismuth	0.06	0.06
Nickel	0.25	0.87
Total..	99.95	99 91

From the readiness with which arsenides and antimonides are formed when highly arsenical and antimonial ores are smelted, as well as the volatility and unstability of the sulphides of these elements, we may assume that these elements replace sulphur in mattes, combining mainly with iron and nickel. The other common elements probably occur as sulphides.

The exact form of chemical combination in which the various elements occur in mattes could only be determined by a laborious series of experiments, but the proportions under consideration are small and do not affect the following generalization that aims at an explanation of the effects of impurities upon the operations of copper-smelting.

The analyses given in Table VI. may be rearranged so as to show the constitution of the materials. This is done in Table VII.

TABLE VII.—*Rearrangement of Data in Table VI. in Order to Show the Constitution of the Materials.*

Components	1	2
	Per Cent	Per Cent
Cuprous sulphide	91.16	45.20
Metallic copper..	0.20	18 25
Iron and nickel sulphides .	7.58	35 99
Bismuth sulphide	0 07	0.07
Iron and nickel arsenide	0.82	0.35
Iron and nickel antimonide.	0 16	0 06
Total	99.99	99.92
Assuming the presence of white metal, 5 Cu_2S, FeS		
	1	2
	Per Cent	Per Cent
White metal..	83 3	50 2
Cuprous sulphide...	14.3	nil.
Ferrous sulphide	nil.	31.0
Metallic copper..	0 2	18.2
Total	97.8	99.4

A comparison of the results obtained from impure mattes (Tables VI. and VII.) with those obtained from similar mattes having the same proportions of copper, but free from impurities (Tables I. and II.), shows that impurities in mattes have a tendency to reduce the proportion of white metal, a fact which has a marked effect upon the treatment of pure mattes. A 75-per cent. copper-matte, obtained from smelting more or less impure materials, will commonly contain less than 2 per cent. of iron; but pure copper-mattes, containing 78 per cent. of copper, will usually have fully 2 per cent. of iron, and it is only after a considerable proportion of metallic copper has been separated out that a matte comparatively free from iron is obtained. We have always experienced greater difficulty in concentrating pure

mattes beyond 70 per cent. of copper, than mattes having the ordinary proportions of impurities.

The data, given above, show that a matte having 72 per cent. of copper, and the ordinary proportions of impurities, contains 14 per cent. of cuprous sulphide, which is ready for reduction to metallic copper, and 83 per cent. of white metal, whereas a pure matte of similar grade contains only 2 per cent. of cuprous sulphide and 97 per cent. of white metal. It is probable that practically the whole of the white metal must be decomposed before metallic copper can form in any considerable proportion, and, as impurities apparently have the effect of decreasing the proportion of white metal in any grade of matte, the effect of these impurities will be to facilitate the separation of metallic copper. This effect is entirely upheld in practice.

V. Conclusions.

We have deduced the following conclusions concerning the constitution of mattes produced in copper-smelting.

1. Cuprous and ferrous sulphides combine to form a chemical compound corresponding to the formula $5\ Cu_2S, FeS$. We have called this compound white metal.
2. White metal enters into the composition of all mattes.
3. Fused white metal is capable of mixing with all proportions of fused ferrous sulphide, and these constituents separate independently of each other during the solidification of the mixture.
4. All mattes containing an excess of ferrous sulphide are, by virtue of the presence of this compound, capable of dissolving metallic copper which may or may not separate out according to the degree of saturation of the ferrous sulphide.
5. Fused white metal and fused cuprous sulphide mix together in all proportions, but it is only from mixtures in which white metal is in small proportion that metallic copper is readily separated by processes of oxidation.
6. Fused mixtures of white metal and cuprous sulphide can hold metallic copper and cuprous oxide in mechanical suspension.
7. Impurities in mattes, by displacing a portion of the ferrous sulphide available for the formation of white metal, reduce the proportion of the latter compound.

Lead- and Zinc-Deposits of the Virginia-Tennessee Region.

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(British Columbia Meeting, July, 1905.)

CONTENTS.

I. Introduction.

The results embodied in this paper are based on a careful field- and laboratory-study of the lead- and zinc-deposits of the Virginia-Tennessee district, begun in the latter part of the summer of 1904 and completed in the spring of 1905, preparatory to the publishing of a State report on them. A separate description of the individual deposits in Virginia is purposely omitted, since I have already described them in considerable detail in a State report.[1] The Tennessee deposits are described here in some detail for the reason that no detailed record of them has yet been published. Practically, this paper summarizes the results obtained from a study of the geology of the ore-deposits of the district as a whole. (I had the pleasure of visiting the deposits of Virginia and Tennessee with Dr. H. Foster Bain of the U. S. Geological Survey, in April, 1905. Figs. 21 and 22 are from photographs taken by Dr. Bain.)

II. Historical.

The first authentic records of lead-mining in Virginia date back more than 150 years, and the old lead-mines at Austinville, on New river in Wythe county, Va., were the first to be worked. Colonel Chiswell, a native of Wales, and one of the earlier adventurers in southwestern Virginia, was among the first operators of the Austinville mines. Chiswell's operations at Austinville commenced in the year 1750, and closed shortly after the beginning of the Revolutionary War, in the year 1776, covering a period of about 25 years. From that time to the present, mining has been carried on almost continuously in the Virginia area.

For many years after the Virginia mines were operated, mining was confined exclusively to the lead-ores. The zinc-ores

[1] Lead- and Zinc-Deposits of Virginia, *Bulletin No.* 1, *Geological Survey of Virginia*, 159 pages (1905).

seem not to have been recognized at the Austinville mines until some time during the Civil War, when several tons were shipped to the smelting-works at Petersburg, Va.

Zinc-ores were first discovered at Bertha, near Austinville, in Wythe county, Va., during the year 1866. Mining of zinc-ores in Virginia properly dates from the opening of the mine at Bertha in 1879, at which time a small shipment of ore was made to Providence, R. I. The metal obtained from these ores proved to be of such rare purity that attention was directed at once to them, and a smelting-plant was built at Pulaski, Va., which was later remodeled and enlarged, and it is owned and operated at present by the Bertha Mineral Co. The "Bertha" spelter is of exceptional purity and has a world-wide reputation.

The records seem less complete for Tennessee than for Virginia. So far as I have been able to ascertain, the mines northeast of Knoxville, at Jefferson City (Mossy Creek), were the first to be opened in Tennessee (1858), but they were not worked until the year 1866 or 1868. Not until the year 1881, however, was serious mining begun in the Tennessee area. When zinc-ore was first discovered at Mossy Creek, in 1858, several thousand pounds of the ore are reported to have been shipped to the New Jersey zinc-works at Newark for testing. The later development of these mines in 1868 was the result of the test on the above shipment of ore.

III. General Geology.

Only those features of the general geology, which are essential to the understanding of the ore-deposition, will be considered here. The rocks included within the limits of the zinc- and lead-region of Virginia-Tennessee range from Lower Cambrian to Carboniferous in age. They are, without exception, of sedimentary origin; and include shales, sandstones, conglomerates and limestones, presenting considerable variety in composition and in appearance. They have been more or less metamorphosed, and in consequence are considerably changed, as a rule, both lithologically and structurally.

The ore-bearing formation in Virginia is the Shenandoah limestone, and in eastern Tennessee its equivalent, the Knox dolomite, of Cambro-Ordovician age. The formation is a magnesian limestone, dark to light gray or nearly white in color, usually

fine-grained and massive, and containing much chert distributed through parts of it in the form of nodules and layers. Over large areas, especially in Tennessee near Clinch and Powell rivers, some layers are coarsely crystalline, in fact they are marble. Wide variation in composition is noted from slight siliceous marble to calcareous sandstone.

Folds and faults characterize the entire area of the Great Valley of the Virginia-Tennessee district. The folds have a general trend paralleling approximately the axis of the valley, which is NE–SW. in direction. The dips on the western side of the anticlines are frequently vertical, and, in places, overturned; and many of the folds have been compressed until broken. In the Tennessee area, Keith says that the dips range from flat to vertical and to 50° overturned. The usual dip on the southeast side of a fold is from 30° to 45° to the southeast. The faults are associated with the anticlinal folds, the breaks occurring usually on or near the northwestern side of the anticlines. The faults are of the over-thrust type, with the fault-planes usually dipping from 30° to 50° SE., with an estimated displacement, by Keith, in some of the faults of the Tennessee area, of nearly 3 miles. The faulted zone is usually characterized by much brecciation, and it is along these zones that localization and concentration of the lead- and zinc-ores have taken place.

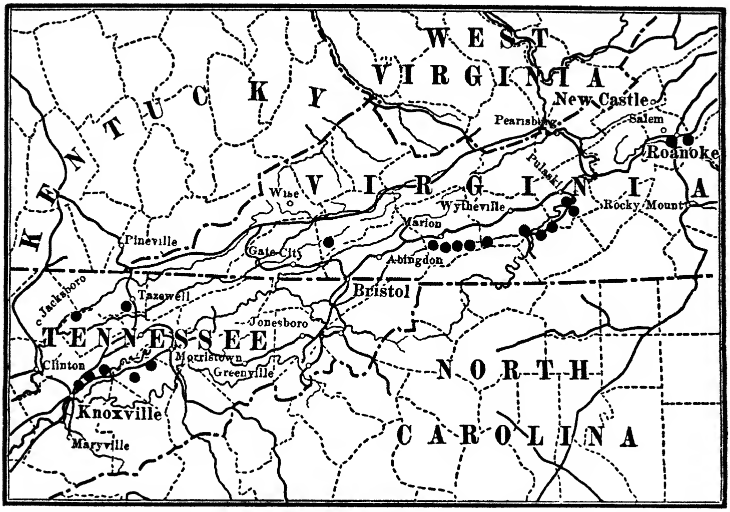
The Appalachian valley has been a land-area since early Mesozoic time, during which time the field-evidence indicates several periods of uplift, followed by intervals of quiescence. The periods of quiescence, which followed each uplift, were sufficiently long to enable the streams to establish a system of base-levels over the entire region; and the region was also stationary for a time sufficient to admit of the inter-stream areas being lowered to an approximately uniform level. The harder and more resistant rocks, such as sandstone and quartzite, were never entirely reduced, but they marked partly unreduced residuals, which stand in relief above the general level of the erosion-plane.

Accordingly, evidence favoring several periods of base-leveling, and planation is recorded over the area. The oldest and most extensive peneplane was probably formed in Cretaceous time. Subsequent uplifts were followed by shorter periods of

quiescence, which record other peneplanes cut during the Eocene and Neocene periods.

IV. Distribution of the Ores.

Geographically, the ores are confined to the valley region of southwestern Virginia and its equivalent in eastern Tennessee, extending from Roanoke, Va., southwestward to Knoxville, Tenn., as indicated on Fig. 1. Isolated deposits of the ores are found further south and west in Tennessee. Not all of the



Scale, 1 inch = 120 miles.

Fig. 1.—Map of Southwestern Virginia and Eastern Tennessee, Showing Distribution of Lead- and Zinc-Ores. Lead- and Zinc-Deposits are Indicated by Heavy Dots.

above area contains workable deposits of lead and zinc, but, up to the present time, the productive areas are confined within the limits of two or three counties in each State. Numerous isolated single prospects have been opened, away from the productive centers, within the valley region of both States.

Geologically, the ores are confined to a single formation, magnesian limestone of Cambro-Ordovician age, known as the Shenandoah limestone in Virginia, and the Knox dolomite in Tennessee. The Shenandoah limestone is correlated with the Knox dolomite, and it includes, in addition, at least 1,500 ft. of Cambrian strata beneath the Knox dolomite.

V. The Ores and Associated Minerals.

The minerals of the lead- and zinc-region in Virginia and Tennessee are not numerous in species, but they are confined chiefly to a few of the commoner forms. They include (1) the original sulphide forms, sphalerite, galenite, pyrite and, in one or two places, chalcopyrite; and (2) the secondary or oxidized forms which have been derived from the original sulphides and occur in the residual decay of the limestone. These include calamine, smithsonite, cerussite and limonite.

The associated non-metallic minerals, named in the order of their importance, are dolomite, calcite, barite, fluorite and quartz. Of these, dolomite and calcite constitute the principal ones, and they occur in vastly the largest amount. Barite, fluorite and quartz, though not observed in the Tennessee area, have been found in several places in the Virginia area.

1. *The Lead-Ores.*

(a) *Galenite.*—The principal occurrence of galenite is in association with the zinc-ores in the zinc-mines. The association of galenite and sphalerite seems to be more general in Virginia than in Tennessee. At a number of the zinc-mines in Tennessee, and at a smaller number in Virginia, galenite is practically absent; while in others it occurs in fairly large amounts in intimate association with the sphalerite. It is reported to be the principal ore at several places in Tennessee. Its usual occurrence is granular and massive-granular, less frequently in the form of crystals. Selected specimens from the Austinville lead- and zinc-mines, Wythe county, Va., gave the following results on analysis:

Lead (Pb),	73.89	equivalents		
Zinc (Zn),	9.31		PbS,	85.29
Iron (Fe),	0.22		ZnS,	13.87
Sulphur (S),	16.20		FeS_2,	0.46
Silica (SiO_2),	0.54			
Total,	100.16			

(b) *Cerussite.*—Cerussite has been found, in more than a trace, only at one locality, namely, the Austinville mines in Wythe county, Va., where it is not an altogether uncommon ore among the altered forms. During the period of early mining

in eastern Tennessee, cerussite was noted as one of the altered ores occurring in the residual decay in several of the mines. It occurs distributed through the residual clays of the limestone as stringers and small irregular masses. The earthy form greatly predominates, this clayey admixture being readily identified by its weight. Crystals, grouped in clusters and aggregates of white and light grayish color distributed through the clay, are not uncommon. It also occurs as a white, powder-like coating on the crystals and masses of granular galenite.

2. *The Zinc-Ores.*

(a) *Sphalerite.*—This mineral, constituting the most important ore over much of the Virginia-Tennessee district, was the original zinc-mineral from which the secondary zinc-ores, concentrated above ground-water level, have been derived. It is found usually below the level of ground-water, and, in some of the mines not yet worked to this depth, it has been found but sparingly. It varies in color from yellow, through brown, to nearly black; the black color being due to impurities, particularly iron. In some of the larger mines sphalerite is associated with much galenite, in places; some pyrite, and very occasionally with scant chalcopyrite.

The occurrence of sphalerite is in the form of disseminated grains, masses and stringers, in the magnesian limestone; and in similar form, but mostly as stringers, in quartz-fluorite lenses intercalated in a crinkled, talcose schist, in Albemarle county, Va. At Cedar Springs, Wythe county, and Rye Valley Smyth county, Va., the blende is of exceptional purity, as indicated in the analyses below. It is of yellow color, massive in form, with perfect cleavage, but not preserving outward crystal form. At other localities in Virginia and Tennessee, the blende is less massive in form, and occurs mostly as disseminated grains.

The character of the blende over the Virginia area is indicated in the following analyses from selected pieces collected from the mines in Albemarle, Wythe and Smyth counties.

*

	Austinville, Wythe County. Per Cent.	Cedar Springs, Wythe County. Per Cent.	Rye Valley, Smyth County. Per Cent.	Albemarle County. Per Cent
Zinc,	65.01	66.76	66.94	62.11
Sulphur,	31.93	33.44	33.26	34.45
Iron,	1.94	0.50	0.30	3.44
Lime,	0.08	trace	trace	0.05
Magnesia,	none	trace	trace	none
Silica,	0.33	0.10	0.08	0 26
Total,	99.29	100.80	100.58	100.31
Zinc sulphide,	96.94	99.56	99.86	92.70

(b) *Smithsonite.*—In some of the mines, especially in Virginia, smithsonite forms a fairly important ore of zinc. It occurs in the residual clays derived from the magnesian limestone, concentrated usually in the bottom portions of the clays, and resting immediately on the irregularly weathered surface of the limestone, as is shown in Figs. 2 and 3. It is intimately associated with calamine.

Smithsonite occurs both in the granular and earthy form, principally the latter, as crystalline incrustations, and as a porous or spongy material with the cavities frequently filled with a powdery and earthy form of the ore. In color it varies from light gray, through yellow, to brown, according to the impurities present.

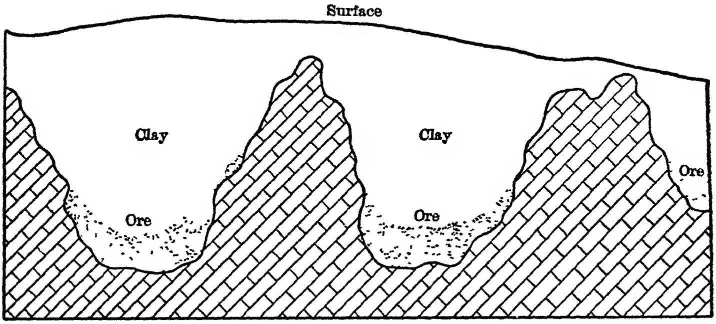
The calculated amounts of smithsonite and calamine, from analyses made by F. P. Dewey on specimens of the ore of the Falling Cliff zinc-mine at Bertha, Va., gave the following results:

	I. Per Cent	II Per Cent
Smithsonite,	75.52	79.99
Calamine,	22.22	12.05

(c) *Calamine.*—Calamine formed originally the principal secondary ore of zinc mined in the district. It is much more abundant than smithsonite. In occurrence it is closely similar to that of smithsonite, with which it is intimately associated. It is indeed very difficult, and in some cases impossible, to separate the two ores, so intimately admixed are they.

Calamine occurs in the residual clays usually in the bottom portions immediately on and next to the irregular weathered surface of the underlying limestone, shown in Figs. 2 and 3. Beautiful white incrustations of the mineral, presenting both

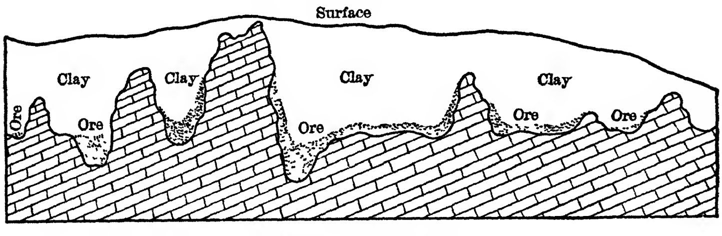
mammillary and stalactitic surfaces, have been observed in places between layers of the more solid massive ore. Granular massive and honey-comb forms of calamine were quite common. Much of the calamine formerly mined at Bertha is re-



Blocked area is limestone.

FIG. 2.—SECTION IN OPEN CUT AT THE AUSTINVILLE LEAD- AND ZINC-MINES, SHOWING THE RELATIONS OF THE SOFT ORE TO THE LIMESTONE "CHIMNEYS" AND THE RESIDUAL CLAY. AUSTINVILLE, WYTHE COUNTY, VA.

ported to have been in sheet form, rarely in contact with the limestone, but concentrated several inches away from the limestone surface, and having the intervening space filled with a mixture of loose powdery calamine and smithsonite.



Blocked area is limestone.

FIG. 3.—SECTION IN OPEN CUT AT THE BERTHA ZINC-MINES, SHOWING THE RELATIONS OF THE SOFT ORE TO THE LIMESTONE "CHIMNEYS" AND THE RESIDUAL CLAY. WYTHE COUNTY, VA.

The following chemical analyses of specimens of calamine from the mines in Wythe county, Virginia, indicate the general character of the ore.

	I. Per Cent.	II. Per Cent.	III. Per Cent.
Zinc oxide,	67.88	67.42	67.15
Silica,	23.95	25.01	25.33
Water,	8.13	8.32	7.47
Total,	99.96	100 75	99.95
Sp. Gr.,	3.338	....	3.40

I. MacIrby, *Chemical News*, 1873, vol. xxviii., p. 272.
II. Genth, F. H., *Proceedings of the American Philosophical Society*, 1885, vol. xxiii., p. 46.
III. Jones, A., *Journal of the American Chemical Society*, 1882, vol. vi., p. 620.

Calculated amounts of calamine and smithsonite, from analyses made by F. P. Dewey on specimens of the ore from the Falling Cliff zinc-mine, at Bertha, Va., gave the following results:

	Per Cent.
Calamine,	88.52
Smithsonite,	3.26

(d) "*Buck-fat.*"—Buck-fat is the name applied by the miners to a mixture of clay with the minerals, calamine and smithsonite. It is not a definite mineral, but is a lean ore, generally too low in zinc to be profitably used in the present practice of smelting. The zinc-content shows wide variation, however, ranging oftentimes much higher than that given in the analysis below. It is both hard and soft, and is accordingly called by the miners "hard buck-fat" and "soft buck-fat." Its separation from the rich ores is effected by hand-sorting and by subsequent washing and jigging. The treatment practiced at the Bertha mines, Va., previous to the conversion of the ore into spelter, consisted in violently washing the soft buck-fat in water, and crushing and jigging the hard buck-fat.

Heyward gives the following analysis of a zinc-bearing clay from the neighborhood of the Bertha mines, Virginia.

	Per Cent.
Silica,	37.38
Alumina,	24.67
Ferric oxide,	6.34
Zinc oxide,	12.10
Magnesia,	0.27
Potash,	0.47
Soda,	0.27
Water below 100° C.,	6.69
Water above 100° C.,	10.35
Total,	98.54

3. *Associated Ores.*

Over the Virginia area, iron-ores and manganese-ores, especially the former, are very abundant in some of the larger zinc-mines. The iron-ores have been somewhat extensively mined in places, and in several instances mines, formerly worked for zinc-ores, are now being worked for iron. Pyrite is rather a frequent associate of galenite and sphalerite in some of the Virginia mines. It occurs in the fresh limestone below the belt of oxidation. It is by no means uniformly distributed through the rock, but in places it is sufficiently concentrated to be noticeable, and rarely, if ever, is it present in quantity large enough to be hurtful to the lead- and zinc-ores. Limonite comprises the principal iron-ore mined in association with the zinc-ores. Hematite is less common than limonite. The black oxide of manganese frequently occurs in some of the mines, but at no place has it been found in quantity sufficiently large to attempt the saving of it.

4. *Associated Minerals.*

The associated minerals are limited both as to species and occurrence. Named in the order of their importance they are,—dolomite, calcite, fluorite, quartz and barite. Of these, dolomite and calcite comprise the minerals associated with the ores in the Tennessee area. In addition to these, which form the principal minerals in the Virginia area, fluorite, quartz and barite occur. Fluorite and quartz constitute the gangue minerals at the zinc- and lead-mine in Albemarle county, Va. Calcite occurs only sparingly at this mine, while fluorite is the dominant mineral. In the mines of southwestern Virginia dolomite and calcite comprise the dominant minerals, with some barite and less fluorite. Here, and over the Tennessee area, the dolomite and calcite fill the fractures between the magnesian limestone fragments in the form of crystalline masses, forming a limestone breccia. The relative proportions of cement (recrystallized calcite and dolomite) to rock fragments vary widely.

(a) *Dolomite and Calcite.*—These minerals occur intimately admixed in massive crystalline form, filling the fractures between the broken limestone fragments, which cement them together as breccia. They are prevailingly white in color, and

frequently occur in perfect cleavable masses of the rhombohedral type. Numerous analyses of specimens of the calcite and dolomite collected over the Virginia-Tennessee district gave nearly pure calcium carbonate for the former, and a ratio of calcium to magnesium of 1 : 1 for the latter, which is the ratio of normal dolomite.

(b) *Fluorite.*—At the mines in Albemarle county, Va., fluorite, the predominant mineral, occurs in both large and small lenses in the crinkled schist, and it is usually of white color, though

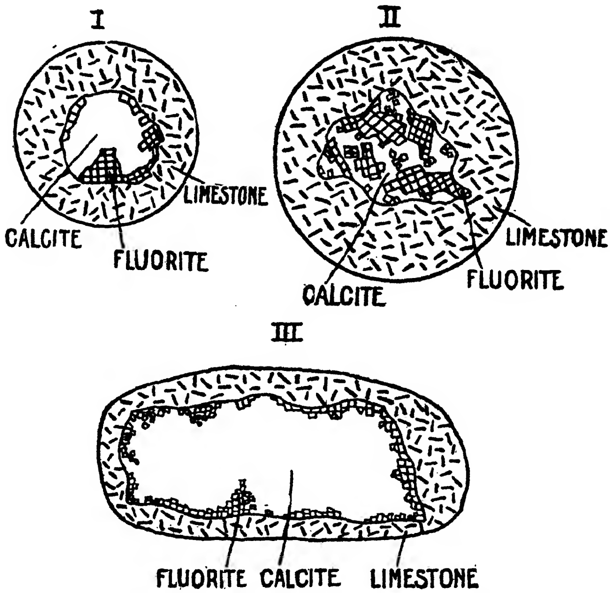


Fig. 4.—Cavities in Magnesian Limestone Filled with Calcite and Fluorite, Showing the Relations of the Two Minerals to Each Other. McCarter Place, Rye Valley, Smyth County, Va.

the violet shade is fairly common. This mineral has been sparingly found at several localities in southwestern Virginia in association with the metallic sulphides, but as yet it is unknown in the Tennessee area. In the Virginia mines it occurs in three forms:—distributed through and enclosed by the blende; distributed through the dolomite and calcite filling of the limestone breccia; and in association with dolomite and calcite, filling and lining small cavities in the limestone, as shown in Figs. 4, 5 and 6. Lastly, fluorite was sparingly noted

at the mine of the Rye Valley Mining Co., near Sugar Grove, Va., as a coating in association with calcite and dolomite

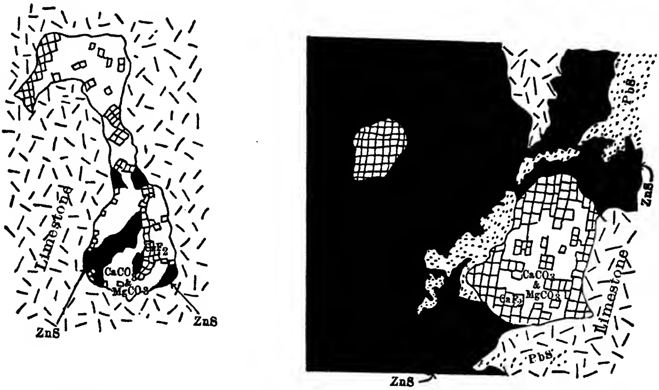


FIG. 5.—SKETCH, SHOWING RELATIONS OF SPHALERITE AND GALENITE TO FLUORITE AND CALCITE-DOLOMITE. RYE VALLEY MINING CO., SUGAR GROVE, SMYTH COUNTY, VA.

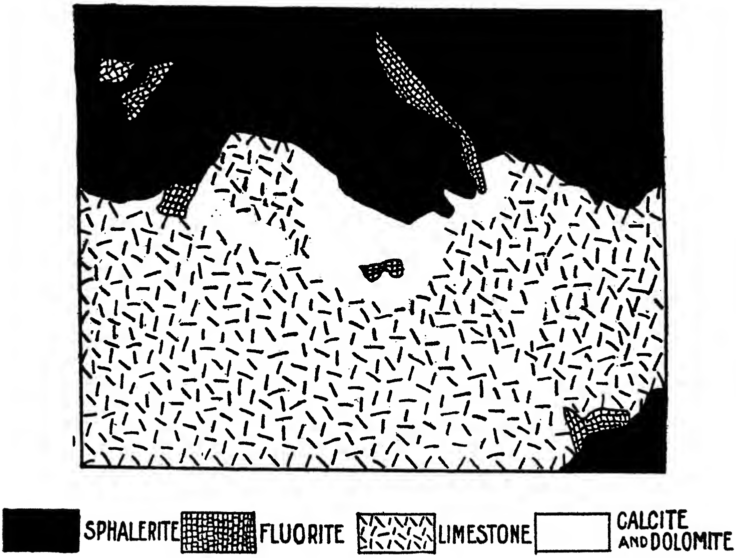


FIG. 6.—LIMESTONE BRECCIA FROM THE CEDAR SPRINGS ZINC MINING AND DEVELOPMENT COMPANY'S OPENINGS, SHOWING THE RELATIONS OF FLUORITE TO SPHALERITE, AND TO THE CALCITE-DOLOMITE FILLING. NATURAL SIZE. CEDAR SPRINGS, WYTHE COUNTY, VA.

on the slickenside surfaces and parting-planes of the limestone.

(c) *Quartz.*—The mineral quartz is found in direct association with the zinc- and lead-ores only at the zinc- and lead-mine in Albemarle county, Va. It is admixed with fluorspar as fluorspar-quartz lenses, which contain the lead- and zinc-ores distributed through them. Quartz is very much less abundant than fluorspar. Quartz, in the form of chert, is abundantly distributed through the lead- and zinc-bearing magnesian limestone of southwestern Virginia and eastern Tennessee, but the chert is rarely or never seen in close association with the ores.

(d) *Barite.*—This mineral is common in the limestone region of southwestern Virginia, and it has been mined in several places, but it is not associated with the lead- and zinc-deposits except at two of the mines. It has been observed in small quantity at the Bertha zinc-mine, and it was very abundant at the mines of the New River Mineral Co., west of Ivanhoe. At the latter place a little of the blende was observed to be enclosed by the barite-filling of the limestone.

VI. Alteration of the Lead- and Zinc-Ores.

The important secondary ores comprise calamine, smithsonite and cerussite, which have been derived from the original sulphides, galenite and sphalerite, by oxidation, carbonation, silication and hydration above or near ground-water level. Only the oxidized or secondary ores have been mined, but every preparation is now being made to mine the original sulphide ores in the fresh limestone.

1. *The Zinc-Ores.*—Below the ground-water level, in the fresh limestone, the mineral form of the zinc-ore is the sulphide, sphalerite. Above this level, in the belt of residual decay, only the altered forms, the oxidized ores of zinc, are found,—calamine and smithsonite; the former always predominating. Smithsonite is found in larger quantity in some mines than in others. Unaltered sphalerite seems not to occur in the decay of any of the mines, but it is replaced instead by the two oxidized forms mentioned above.

Portions of the country-rock next to the bottom portions of the loose decay, originally containing grains and crystals of the sulphide ores, sphalerite and galenite, are now porous and open-textured in many places,—a condition resulting from the removal of the sulphides in solution. Frequently, where the

alteration has been complete, the rock apparently is extremely cavernous and presents a typical honey-comb appearance. Yet, in other places, the ores have been observed in the limestone in various stages of oxidation, and the cavities left are either entirely vacant or are occupied by a film of iron oxide. In the process of alteration the oxidized ores may be removed a short distance, or they may remain practically in place; usually migration is indicated.

2. *The Lead-Ores.*—Like that of zinc, the mineral form of the lead in the fresh rock is the sulphide, galenite, admixed usually with sphalerite. In the belt of decay, more or less closely associated with the secondary zinc-ores, the oxidized form of lead is cerussite, which is present in very appreciable quantity in the Austinville mines in Wythe county, Va. In addition to the cerussite, more or less galenite, admixed with the secondary ores, occurs in the belt of weathering. Galenite being more difficultly oxidizable than the sulphides of zinc and iron with which it is associated, and being less soluble than the limestone in which it occurs, are circumstances which account chiefly for the presence of galenite in association with the secondary ores in the zone of weathering.

The cerussite is sometimes observed coating or incrusting the galenite, and occasionally it has been noted in small crystals on the galenite. In some specimens of the galenite not incrusted by the alteration-product, cerussite, the surfaces appear dull, and are much roughened, being pitted by etching. The same specimens, when broken, show the bright metallic luster of the unaltered galenite on the inside. A few specimens were noted which were apparently all cerussite, but, on breaking, they proved to be only partly altered; the outer portions of the original galenite being entirely coated with a variable thickness of the lead carbonate, and the inner part composed of fresh unaltered galenite. In still other specimens, limited to the zone of weathering, the alteration seemed complete, with no trace of the original sulphide indicated. Between these two extremes of alteration nearly all gradations were observed.

VII. Mode of Occurrence.

1. *The Sulphide Ores.*—The bulk of the sulphide ores belong to the disseminated replacement breccia type. As a rule, the

process of replacement has played an important part in the ore-formation, but in some instances very little replacement of the limestone by the ore is indicated. In the latter case the ore would be more properly designated a straight breccia-type in which practically no replacement has occurred. On the other hand, the ore has originated at several places over the district largely through a replacement-process.

The breccia is usually made up of sharp-angled fragments of the country-rock, magnesian limestone, cemented by a matrix of white crystallized calcite and dolomite and blende, with or without replacement of the limestone fragments. The breccia-zones are associated with faulting and folding. Not all parts of the breccia-zones are mineralized, but the ore is distributed at somewhat irregular intervals. Where mineralized, and so far as can be judged from developments, the ore continues with depth.

At Austinville, Va., clear crystallized calcite apparently does not occur, but the rock has been largely recrystallized, and small "eyes" of the dark, nearly unaltered, rock are distributed through the new recrystallized portion. Jointing is freely developed, and ore concentration and replacement of the recrystallized limestone by the ores have taken place along the bedding- and joint-planes, mostly where the two sets of planes intersect, forming large and well-defined ore-shoots. Similar bodies of sulphide ores are developed at the Straight Creek mine, near Tazewell, in Claiborne county, Tenn. As elsewhere explained, the process of mineralization at Austinville began, first by filling the fine cracks, and then extending into and replacing the anhedra of dolomite by ore along some crystallographic direction, as illustrated in Figs. 7 and 8.

Where occurring in the same mine, the blende and galenite are intimately admixed. Many parts of the limestone, both small and large, show all blende, with only, here and there, sparing dissemination of galenite through the rock, closely intermingled with the blende. Other parts of the limestone, usually much smaller in area, show a preponderance of galenite with little or no disseminated blende. The same relation holds true for the very small amount of pyrite present in the rock, which may be intermingled with the galenite or blende, or both. The relations between the galenite and blende in the limestone, as described above, are made plain in Figs. 9 and 29.

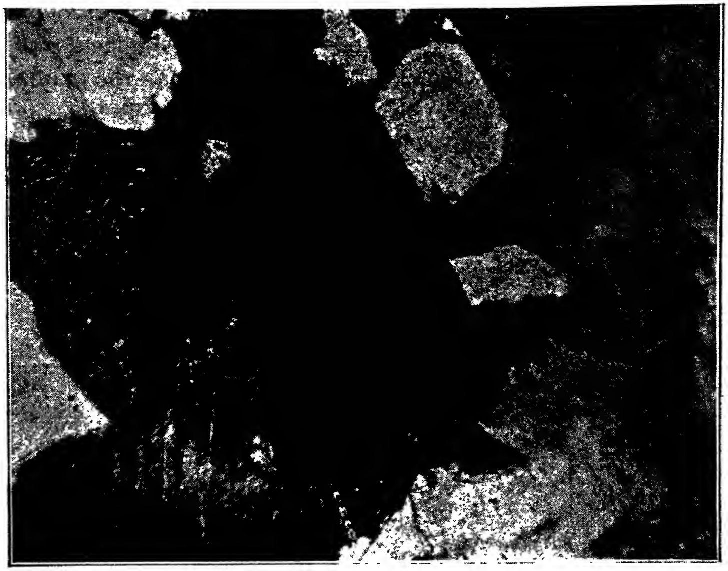


FIG. 7 (A).

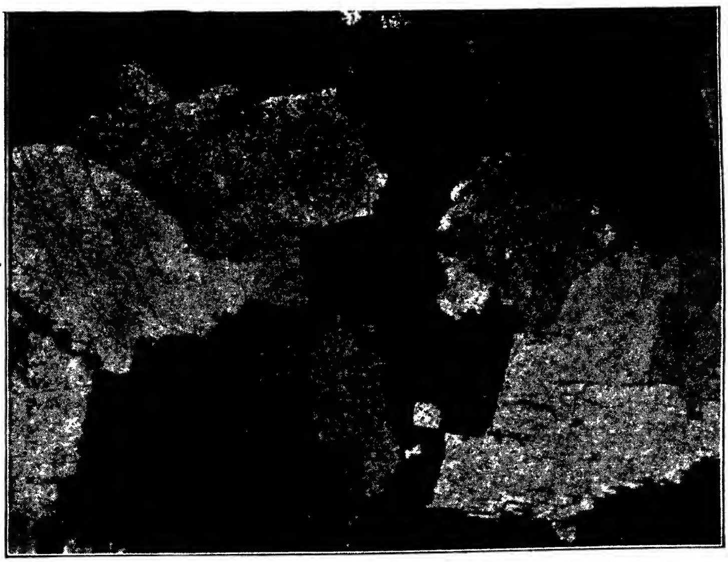


FIG. 8 (B).

PHOTOMICROGRAPHS OF THIN SECTIONS OF SULPHIDE ORE FROM AUSTINVILLE MINES, WYTHE COUNTY. MAGNIFIED 50 DIAMETERS; CROSS NICOLS. Black areas represent sulphide minerals. Shows crystalline character of limestone and its replacement by the sulphides. Re-entrant angles along margins of the sulphides and the spider-like arrangement of the sulphide areas, as a whole, are well shown.

2. *The Oxidized Ores.*—Where sufficient developments have been made, as in the mines of Wythe county, Va., the oxidized ores usually show much richness, and they are often concentrated in massive form as large irregular masses and layers.

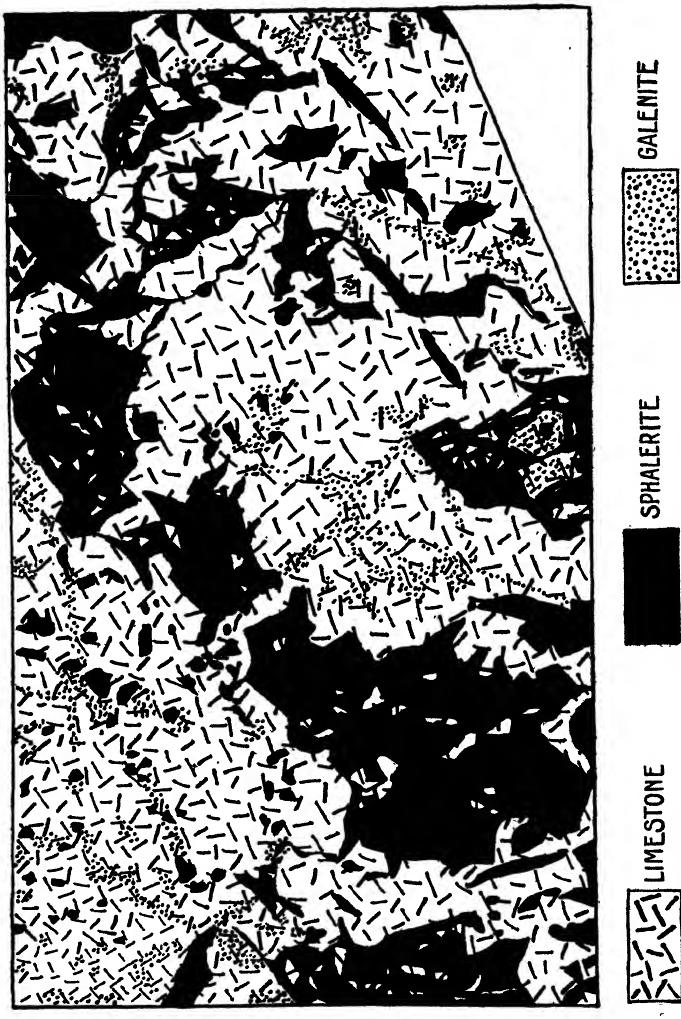


Fig. 9.—Specimen of Typical Ore from Austinville Lead- and Zinc-Mines, Showing Relations of Sphalerite and Galenite to Each Other and to the Limestone. Natural Size.

This is especially true of the calamine, which forms the dominant oxidized ore. So massive was the calamine in places in the old Bertha mines, that blasting is reported to have been necessary for its removal.

Concentration of the oxidized ores has taken place principally at and near the bottom of the residual clays, closely hugging the irregular weathered surface of the limestone, as shown in Figs. 2 and 3. Frequently, several inches separate the massive form of the ores, calamine and smithsonite, from the limestone. This space is filled, oftentimes, with a loose powdery form of admixed calamine and smithsonite. At times, the partly decayed limestone, in pulverulent granular form, partly or entirely fills the space. Much galenite is intermingled in places with the concentrated calamine and smithsonite in the lower portion of the clays. Usually, when associated with the oxidized ores in the way mentioned, the galenite is observed to diminish in quantity upward more rapidly than the calamine and smithsonite.

Smithsonite, which is present in much smaller quantity than calamine, is admixed, as a rule, with the calamine, and both are concentrated in the basal portion of the clays next to the limestone surface. Cerussite occurs largely in stringer-form, penetrating the clays, and as a coating on the masses and nodules of galenite. The stringers of cerussite show considerable variation in thickness and extent, but in the larger ones a nearly vertical position in the clays is often assumed.

As a rule, the residual clays are highly ferruginous. Limonite composes the principal part of the clays in some of the mines, and it was derived, in part at least, from the oxidation of the original sulphide of iron, pyrite, disseminated through the limestone in association with galenite and sphalerite. It is usually of good grade, and it occurs so extensively in some of the mines formerly worked for zinc-ores, that attention is now given entirely to the mining of the iron-ore.

The relations between the ores, the limestone and the clays, as described above, are shown in Figs. 2 and 3.

VIII. Paragenesis and Association.

No definite order of deposition of the original minerals could be positively determined. The metallic sulphides, lead, zinc and some iron, and the gangue minerals, seem to have been introduced and crystallized at about the same time. The three sulphides, when present, are usually so intimately mixed as to preclude any attempt at determining the order of deposition.

Variations in the association of the metallic sulphides and the gangue minerals, and the relations of these to the enclosing rock, are shown.

A common association is the more or less replacement of the country-rock, on one or both sides of a fracture, by the sulphides, and the filling of calcite and dolomite without metallic sulphides distributed through it. In places, the broken fragments of limestone are either partially or completely rimmed by narrow bands of sphalerite, as shown in Figs. 10 and 11. At times, both forms of filling rudely resemble banding on a

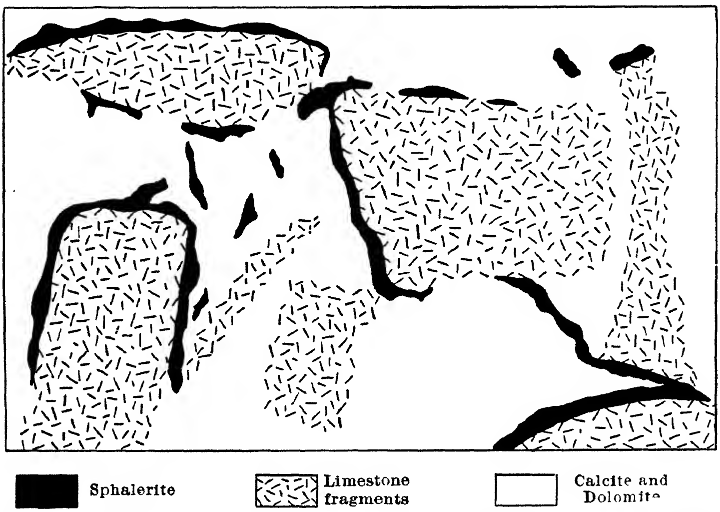


FIG. 10.—BRECCIATED LIMESTONE CEMENTED WITH CALCITE AND BLENDE. LIMESTONE FRAGMENTS PARTIALLY RIMMED BY BLENDE. SKETCHED FROM SECTION OF OPEN-CUT WALL, MOSSY CREEK MINES, JEFFERSON CITY, TENN.

small scale, in which it appears that the sulphides were perhaps introduced somewhat in advance of the gangue-filling. When it is remembered, however, that all gradations are observed between this form of filling and those stated next below, where the evidence seems conclusive for contemporaneous deposition, it seems reasonable to assume that deposition of the ores and the associated minerals for the district, as a whole, was made at about the same time. Moreover, cases are observed in which calcite and dolomite are entirely enclosed by the metallic sulphides and vice versa. Similar relations of fluorite to the sul-

phides, and fluorite to calcite and dolomite are observed. Fig. 6 shows that fluorite is entirely enclosed by the calcite-dolomite filling, and fluorite is also entirely enclosed by blende. Again, the filling of very small cavities in the limestone by fluorite and calcite in Rye Valley, Smyth county, Va., shows, in some cases,

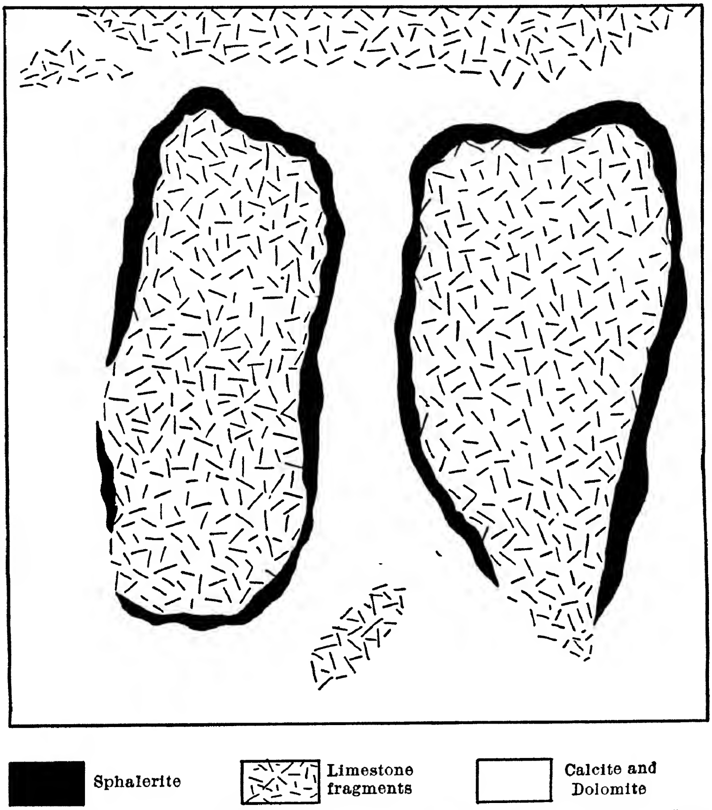


FIG. 11.—BRECCIATED LIMESTONE, SHOWING RIMS OF BLENDE AROUND LIMESTONE FRAGMENTS. DRAWN FROM FACE OF WORKINGS IN MOSSY CREEK MINES, JEFFERSON CITY, TENN.

a somewhat broken, irregular lining of the cavity by fluorite next to the limestone, and the remainder filled in by calcite, as indicated in Fig. 4. This association of fluorite and calcite points to a filling of fluorite in advance of the calcite; but occurring immediately along side of this may be observed a similar cavity filled with intimately admixed fluorite and calcite

from the walling to the center of the cavity, where no doubt exists of the simultaneous deposition of the two minerals.

Equally common, perhaps, is the filling of the fracture in the limestone by metallic sulphides and the gangue minerals, without any replacement of the limestone by the sulphides indicated. In this case the sulphide ores are distributed through the filling of calcite and dolomite. In still other cases the fracture may be filled for its entire width, at intervals along its length, with the sulphides, and the intervening spaces filled entirely with calcite and dolomite, or with a mixture of the gangue and sulphide minerals, as shown in Fig. 12.

Sufficient developments in the fresh limestone are lacking, upon which to base any statement of a grouping, corresponding to a vertical order of succession of the dominant metallic sulphides. The idea prevails over the district, that galenite is more abundant in the upper portions of the rock, and decreases in depth, followed by an increase of blende. So far as developments have gone, evidence is not entirely lacking to support this idea. At Austinville, Va., where mining has been more extensive in the fresh limestone than elsewhere, blende indicates an increase over galenite in depth, although much galenite occurs at the depth thus far reached.

Little or no blende is found within the zone of alteration at the Austinville mines, while galenite is by no means an uncommon mineral within this zone. This is due, however, not to the absence of blende originally in the fresh rock of this zone, but more to the readiness with which blende alters than galenite. Indeed, the large accumulations of the oxidized zinc-ores, calamine and smithsonite, found within the zone of decay, afford every evidence of the presence originally of much blende in the fresh rock of this level.

IX. Secondary Enrichment.

The common evidences of secondary enrichment are wholly lacking in the Austinville mines, but the ore-bodies in the fresh rock are regarded as unmodified ores of primary deposition or of first concentration. Careful study shows the conditions to be against, rather than favorable to, secondary enrichment. Briefly stated, these are: (1) Recrystallization from solution and ce-

mentation of the rock below, resulting in the closing of the original spaces, which precluded the downward circulation of the waters. (2) The absence of lean sulphides necessary to

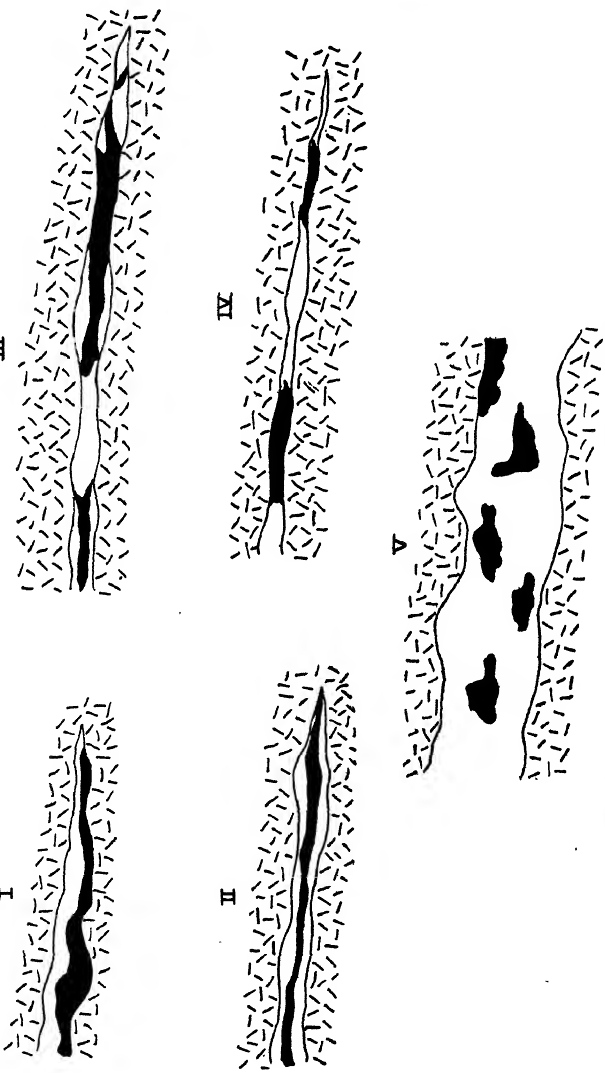


Fig. 12.—Calcite-Dolomite-Sphalerite Filling in Fractures of the Shenandoah Limestone. Shows Relations of Calcite-Dolomite to Sphalerite in Filling of Fractures Over Virginia Zinc District. White is Calcite-Dolomite. Black is Sphalerite. Dash Areas are Limestone. Natural Size.

produce precipitation. Sufficient pyrite in the limestone was lacking to precipitate zinc and lead as sulphides from their oxidized salts; but zinc sulphide as blende was present in places

in sufficient quantity to have precipitated the lead salts as sulphide, had the conditions been favorable to the subsequent downward circulating waters. (3) The conditions favorable to the conversion of sulphates into the carbonates and silicates of zinc, formed from the oxidation of the original sulphide. This follows, in part at least, from the statement made in (1); and, as stated elsewhere, the concentration of the oxidized zinc-ores near and along the irregular weathered surface of the limestone in the bottom portions of the residual clays.

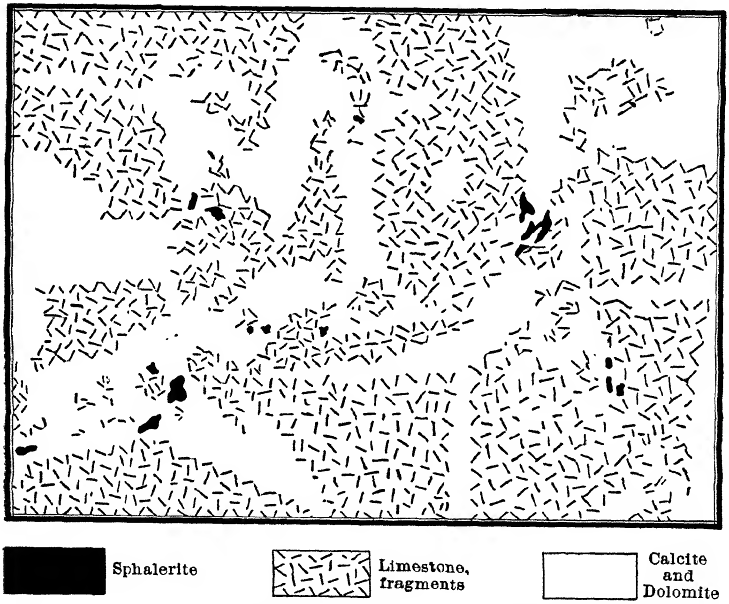


FIG. 13.—BRECCIATED LIMESTONE CEMENTED WITH CALCITE AND DOLOMITE. INGALLS MINES, NEAR NEW MARKET, TENN.

X. RELATION OF THE ORES TO GEOLOGIC STRUCTURE.

As already pointed out, the lead- and zinc-district of the Great Valley region of Virginia-Tennessee is one of intense deformation—folding, faulting and brecciation. Moreover, the localization and concentration of the ores follow closely these structural lines. Mineralization has not taken place through all parts of the breccia-zones, which follow the faulted anticlines; but only along some of the zones, in places and at irregular intervals, have the ores accumulated. Wherever the

ores have been found they have been noted in some part of an anticlinal fold in or near a faulted breccia-zone. The ores are, accordingly, of the breccia-type, as is shown in Figs. 13, 14, 15, 16, 17 and 18. At Austinville, Va., and near Tazewell, Claiborne county, Tenn., the ores appear in well-defined ore-bodies, ore-shoots; and they have resulted largely from a replacement process, mostly where the joint- and bedding-planes of the limestone intersect, and on the limb of a faulted anticline.

At the Austinville mines, in the extreme southern part of

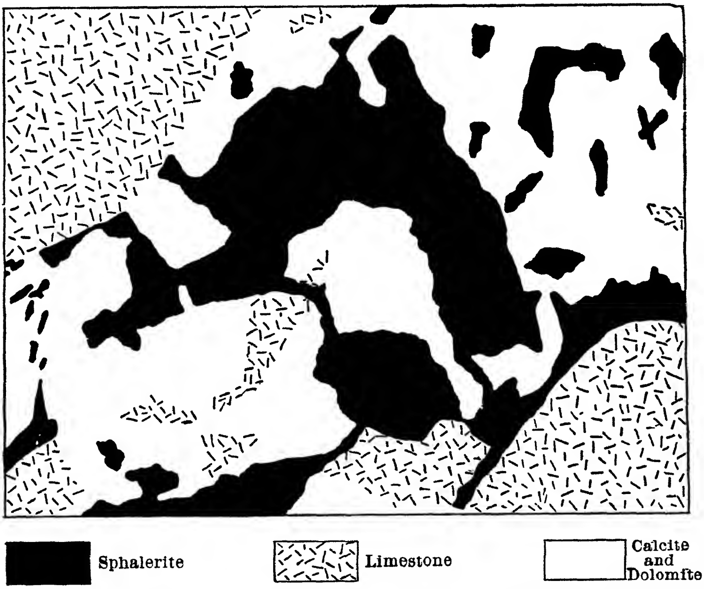


FIG. 14.—BRECCIATED LIMESTONE WITH BLENDE AND CALCITE. ROSEBERRY ZINC-MINES, MASCOT, TENN.

Wythe county, mining-operations have extended to some depth below local ground-water level into the unaltered sulphide ores, sphalerite and galenite. New river cuts across an anticlinal of the Shenandoah limestone near the mines. The accumulation of the ores is in the magnesian limestone strata, which dip about 45° SE., and form the corresponding limb of a faulted anticline. About 8.5 miles east of these mines, on the same (south) side of New river, and about a mile therefrom, are located the Bertha zinc-mines. Here, operations were entirely limited to surface mining of oxidized ores over a belt

about 1,500 ft. wide, extending in the direction of the strike of the limestone, which is south 35° to 40° west. The dip of the limestone, where measured, was 25° NW., with flatter dips reported.

Recent prospecting at Cedar Springs, about 20 miles west of Austinville, in the extreme southwestern corner of Wythe county, Va., indicates that the ores occur on or near the

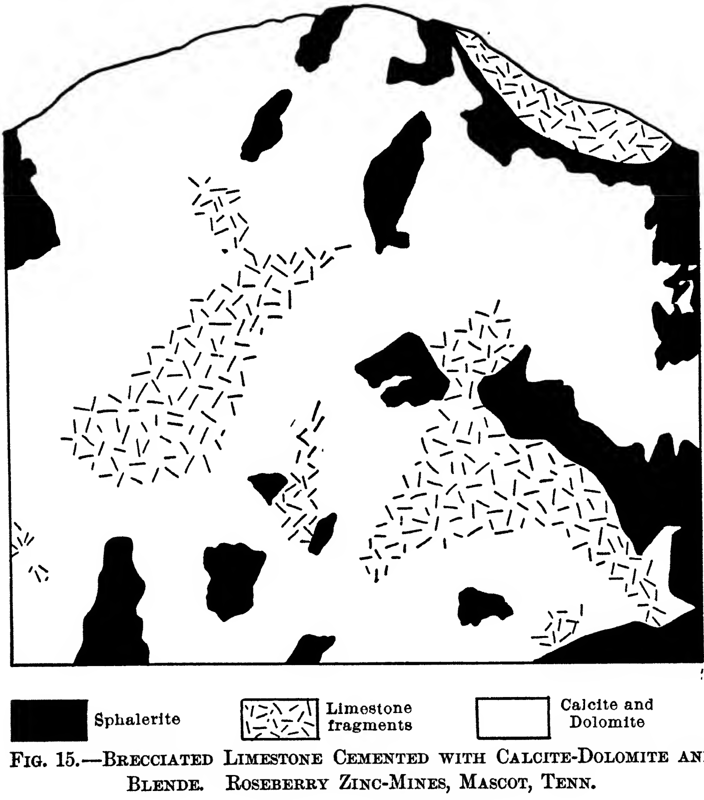


FIG. 15.—BRECCIATED LIMESTONE CEMENTED WITH CALCITE-DOLOMITE AND BLENDE. ROSEBERRY ZINC-MINES, MASCOT, TENN.

faulted crest of an anticline. The distribution, therefore, of the ores in Wythe county is along a narrow belt which crosses the southern part of the county in a north of east direction. This belt is a structure zone—one of anticlinal folding and faulting—and the ores are deposited along and near the fault in the shattered and recemented limestone of the anticline.

Precisely similar relations obtain in the Tennessee part of the district. At New Prospect, formerly known as Lead Mine

Bend, near Powell river, in Union county, Tenn., the ore-bearing area forms a narrow zone trending north 50° E., and lying just south of the crest of the Powell anticline, in which the rocks are crushed and broken.[2] Six miles southwest of Tazewell, in Claiborne county, Tenn., the ore-bodies occur in the lower part of the Knox dolomite, in an area of tilted rocks and near a fault.

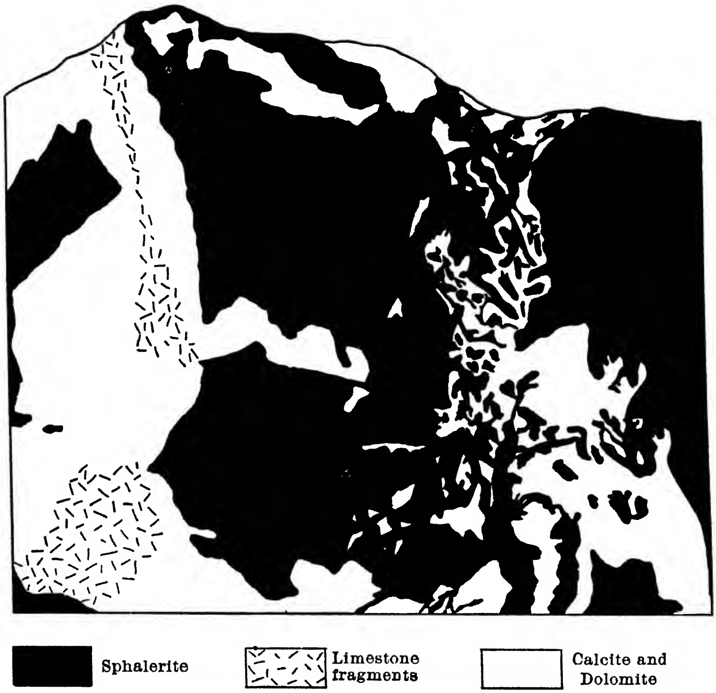


FIG. 16.—BRECCIATED LIMESTONE CEMENTED WITH CALCITE AND BLENDE. MOSSY CREEK ZINC-MINES, JEFFERSON CITY, TENN.

The group of deposits which extend southwestward from near New Market to near Knoxville are apparently located on the same zone of disturbance, several of which are definitely located in broken strata along small anticlines. The Mossy Creek deposit at Jefferson City, in Jefferson county, probably the most extensively mined zinc-ores in the district, occurs in a breccia-zone; the ore filling the crevices in the mass and re-

[2] Keith, Arthur, *Geologic Atlas of the United States, Maynardsville Folio, Tennessee, U. S. Geological Survey*, p. 6 (1901).

placing some of the dolomite. According to Keith,[3] this breccia-zone has nearly a north-south direction, and marks the plane of a large fault.

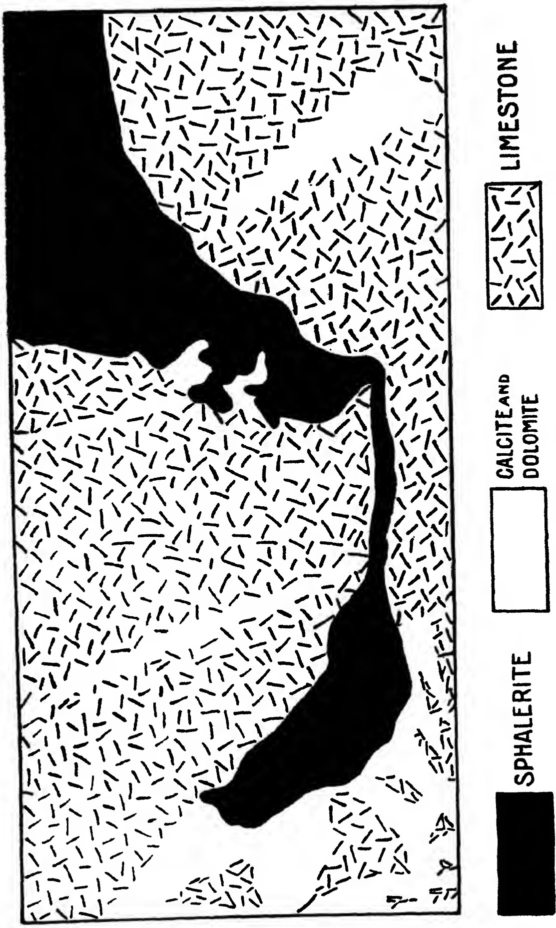


Fig. 17.—Breccia from the Cedar Springs Zinc Mining and Developing Company's Openings, Showing Angular Fragments of Limestone Cemented with Sphalerite, Calcite and Dolomite. Natural Size. Cedar Springs, Wythe County, Va.

XI. Petrography.

The Austinville mines in Virginia are taken as the type-locality of the replacement deposits. The description which here follows is that based on a study of thin sections of the rocks and ores from the above locality.

[3] Keith, Arthur, *Geologic Atlas of the United States, Morristown Folio, Tennessee, U. S. Geological Survey,* p. 5 (1896).

In thin sections, under the microscope, the rock is evenly granular and wholly crystalline, with no admixture of other mineral than dolomite and the ores. The dolomite exhibits both the characteristic cleavage and the twinning, as shown in Figs. 7 and 8. The crystalline grains are filled with minute inclusions, usually of an indeterminable nature. Some of these

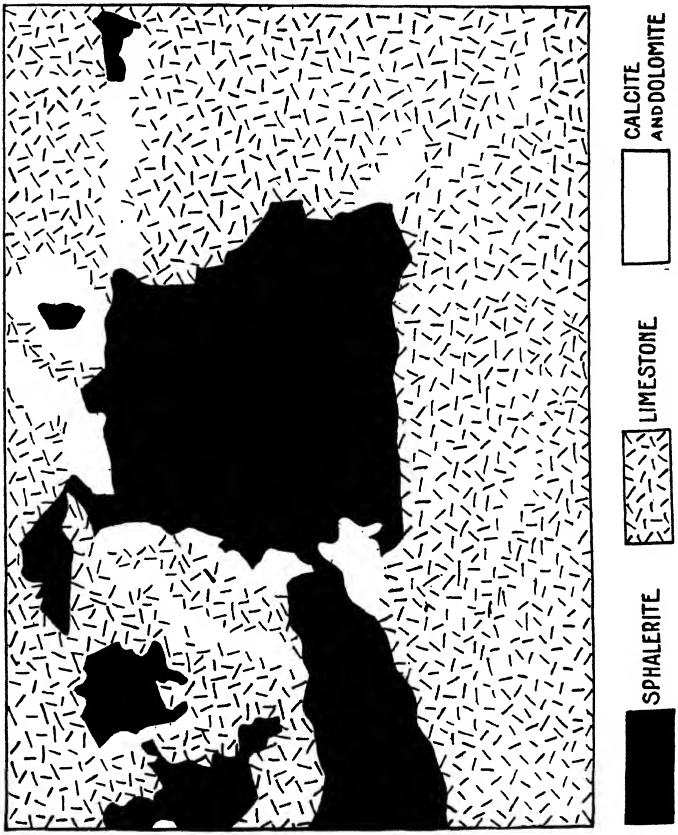


Fig. 18.—Breccia from Cedar Springs, Wythe County, Showing Relations of Sphalerite to Calcite-Dolomite Filling and to the Limestone. Some Replacement of the Limestone by Sphalerite is Clearly Shown. Natural Size.

are of a dark brown and a reddish brown color, and are certainly iron oxide. Frequently, these have accumulated along the sutures between the grains, and extend outward into the substance of the grains, rendering those parts opaque and nearly black to polarized light. Parts of some sections show an opaque yellowish color, due to discoloration from iron oxide staining. In some sections the iron oxide fills the irregular

thread-like cracks, and has been derived from pyrite by oxidation.

Areas of fresh pyrite are distributed through some of the sections, which show characteristic replacement-borders. The peripheries of the pyrite-areas are characterized by re-entrant angles, which correspond to the cleavage angles in the dolomite grains. In some instances a partial cavity is left filled with dark amorphous matter resembling iron oxide—suggesting oxidation of the original pyrite. Galenite shows equally well the evidence of formation by replacement of the dolomite substance along the cleavage-directions. The border portions of the large irregular areas show perfectly straight and sharply-defined edges bounding re-entrant angles, which correspond to the cleavage angles of the dolomite grains. From the margins are given off irregular, long thread-like stringers, which ramify outward into the dolomite substance in spider-like fashion. Some of these fill, in part, the sutures between the dolomite grains, rimming the grains for considerable distances; others fill irregular microscopic fractures in the dolomite grains. This phenomena is typically shown in Figs. 7 and 8.

XII. Weathering.

The Austinville mines in Virginia are again taken as the type-locality because of the extensive mining-operations which expose excellent sections of the fresh limestone and its residual decay for study.

The fresh rock is a recrystallized magnesian limestone. The first and early stage of weathering is a physical crumbling of the crystalline rock into a dolomitic sand, varying from light to brown red in color, in which only slight oxidation is shown. When stripped of its residual decay, the limestone presents an exceedingly irregular pinnacled or "chimneyed" surface, as shown in Fig. 19. The limestone "chimneys" are buried to a variable depth by the decay, with the decay covering the inter-areas, reaching in extreme cases, a depth of nearly 100 ft. The general character of the clays forming the residual covering is red in color and highly ferruginous in composition.

A characteristic feature of the weathered surface of the uncovered limestone "chimneys" is a pronounced irregular pitted aspect, shown in Fig. 20. A close examination of the lime-

FIG. 19.—VIEW IN OPEN CUT OF THE NEW RIVER MINERAL COMPANY'S MINES AT IVANHOE, VA., SHOWING THE TYPICAL PINNACLED OR "CHIMNEYED" SURFACE OF LIMESTONE RESULTING FROM WEATHERING. (H. Ries, photo.)

FIG. 20.—NEAR VIEW OF A PART OF ONE OF THE LIMESTONE "CHIMNEYS," SHOWING THE PITTED AND ETCHED SURFACE FROM WEATHERING ALONG THE BEDDING AND INVISIBLE FRACTURES. (H. Ries, photo.)

stone surface shows this peculiar form of weathering to be due to solution and etching along the irregular fracture-lines in the rock. The weathering of the limestone surface into the characteristic pinnacled or "chimneyed" surface is controlled largely by the jointing of the rock. This form of weathering is characteristic of the openings at Bertha, Austinville and Ivanhoe, Va., and in some of the openings made for mining brown iron-ore. The location of each of these is along the zone of folded and crushed recrystallized limestone. Fig. 21 is a view showing the limestone-weathering in one of the mine openings at Austinville, Wythe county, Va., and Fig. 22 is a view of similar limestone-weathering at the Bertha mine, Wythe county, Va.

The following analyses of the fresh and partially decayed limestone and the residual clay will serve to indicate the changes involved in the transformation of the fresh limestone to the stage of decay represented in the residual clay:—

	I Per Cent.	II Per Cent		III Per Cent.
Lime,	29.77	29.86		0.24
Magnesia,	20.69	20.68		1.02
Alumina,	0.22	0.94		26.27
Ferric oxide,	0.19	0.38		10.53
Manganese oxide,	0.19	0.20		none
Zinc oxide,	none	0.46		none
Soda,	0.50	0.18		undet.
Potash,	0.30	0.05		undet.
Carbon dioxide,	44.43	42.55	(H_2O 110° C. +)	2.06
Water,	3.41	4.06	(H_2O 110° C. —)	7.41
Insoluble matter,	0.42	0.80	(SiO_2)	48.96
Total,	101.12	100.16		96.49

I. Average of three analyses of the fresh crystallized magnesian limestone, Austinville, Va., Dr. W. E. Barlow, analyst.

II. Average of three analyses of dolomitic sand derived from the crystallized magnesian limestone, Austinville, Va., J. R. Eoff, Jr., analyst.

III. Analysis of deep red residual clay derived from the crystallized magnesian limestone in the open pits of the Austinville mines, Va., J. R. Eoff, Jr., analyst.

On comparing these analyses, essentially no difference is shown in the principal constituents of specimens I. and II., which clearly indicates that the early stage in the weathering of this limestone is purely a physical one, and is unaccompanied by any appreciable chemical action. In the next or final stage

FIG. 21.—VIEW SHOWING LIMESTONE WEATHERING IN ONE OF THE MINE-OPENINGS AT AUSTINVILLE, WYTHE COUNTY, VA.

FIG. 22.—VIEW SHOWING LIMESTONE WEATHERING IN ONE OF THE MINE-OPENINGS AT BERTHA, WYTHE COUNTY, VA.

of the decay, shown in specimen III., the results are markedly different; the more refractory constituents, which are present in the fresh rock in barely more than traces, are retained as the principal ingredients composing the residual clay. The carbonates of lime and magnesia, which practically make up the fresh rock, have suffered most from solution and removal, and are only present in the residual clay in very small amounts.

XIII. Age.

Since the ores have been shown to follow rather closely the faulted breccia-zones, they were formed after the period of deformation which resulted in the folding, faulting and shattering of the limestone near and along the lines of breakage. This period of deformation probably dates back to late in, or after the close of, the Carboniferous. The original sulphide ores must antedate the secondary ores, since the latter were derived from the former by the usual processes of atmospheric decay. The altered or secondary ores originated with the periods of peneplanation of which there were several, the earliest and most extensive one being of Cretaceous age, followed by later and less extensive ones cut during Eocene and Neocene times. The original sulphide ores may be as old as the Permian or as young as late Mesozoic, but evidence is lacking with which to fix their age more definitely.

XIV. Origin of the Ores.

The statements here made concerning the genesis of the zinc- and lead-ores apply only to the Great Valley region of Virginia-Tennessee, and not to the single deposit east of the Blue Ridge, in Albemarle county, Va. The conditions, here, are totally unlike those of the Great Valley region. In the Albemarle county area, the ores occur in crystalline schists, and their genetic relation to igneous masses is fairly well established, while the deposits of the Great Valley region are as definitely shown not to have any relation whatever to igneous rocks.

So far as known, there are no igneous intrusions found within the limits of the Great Valley region of Virginia-Tennessee with which to connect the ores. While it is true the ores are related to the folding and faulting of the region, there appears

no good reason for regarding the ores as having been derived from profound depths within the interior of the earth, and later introduced into the limestone from solutions. Indeed, the evidence is against this source of the material, for, when ore-deposits have been formed by such a process, they are usually associated with a characteristic set of minerals, such as compounds of arsenic, antimony and silver, and frequently by fluorspar, etc., all of which, with the exception of barely more than a trace of fluorspar, are entirely absent.

The Cambro-Ordovician limestone is the only formation in the district that is positively known at present to contain lead- and zinc-ores. Other limestones have good development over parts of the district, and apparently offered equally as good advantages for ore-deposition as the Cambro-Ordovician. There appears no real reason why the lead- and zinc-deposits should have been deposited in one formation and not in another, except that the source of the material was limited to the single formation in which they have been concentrated and localized, and in which they are now found. It further seems unnecessary to refer to highly-heated waters either from profound depths or from connection with igneous intrusions as a source of the material, since, as already stated, the field-evidence is against such a process. This evidence favors the original deposition of the ores in the Cambro-Ordovician limestone in disseminated form, but so very sparsely disseminated as to render the deposits unworkable. Subsequent localization and concentration of the ores by underground waters along certain structural lines, previously indicated, has resulted in their present workable form. In some of the Virginia deposits, the ores are intimately associated with the more carbonaceous layers of the limestone, and similar associations of the ores with limestone containing organic matter have been indicated for other deposits in Virginia and Tennessee. These associations indicate that the ores were probably introduced as sulphates, and were reduced by the organic matter in the limestone and deposited as sulphides.

In addition to the sulphate cycle, it seems probable that there was a second or sulphide cycle in which the metals were transported as soluble sulphides and were deposited as such. This was probably the process of deposition at Austinville, and in some other of the Virginia deposits.

Many of the typical breccia-deposits show only slight or little replacement of the substance of the limestone-fragments by the ores, but the ores were introduced and deposited with the calcite-dolomite filling, which cement the broken rock-fragments. Other deposits, like those at Austinville, Va., and Straight Creek, Tenn., take the form of definite ore-shoots, which have resulted largely by a replacement-process, principally along the intersections of the joint- and bedding-planes. The mingling of the ore-bearing solutions with other solutions in the faulted breccia-zones, and the reaction of the ore-bearing solutions on the wall-rock, limestone, largely resulted in the precipitation of the ores, where not connected with reduction and precipitation by organic matter.

As has already been pointed out, the ore-deposits are associated with the folding and faulting of the limestone, following rather closely the brecciation of the rock produced by this deformation. This produced channel-ways in the limestone ready for the free circulation of the underground water, and it was along these directions that the conditions were favorable to the precipitation and deposition of the metallic sulphides.

XV. The Virginia Deposits.

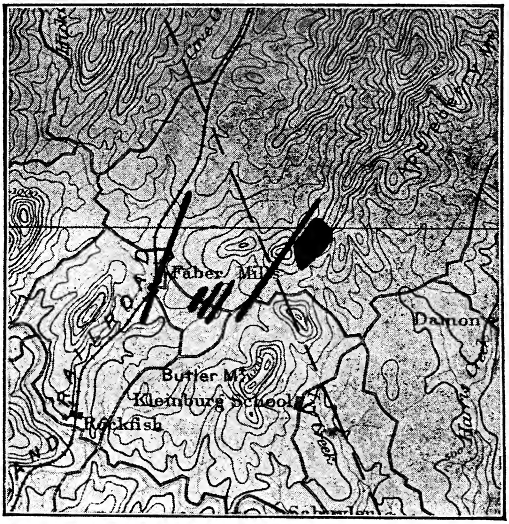
With one exception, the workable deposits of zinc- and lead-ores are confined to the Valley region of southwestern Virginia, which I have already described in much detail in my report, The Lead- and Zinc-Deposits of Virginia,[4] hence they need not be repeated here, particularly since they are closely similar to the Tennessee deposits, which form a part of the same area and are described below.

The single deposit of lead- and zinc-ores in Albemarle county, Va., does merit description here, since it marks the only type of its kind in these metals known in the entire south. The mine owned by the Albemarle Zinc and Lead Co. is located 2 miles slightly north of east from Faber, a station on the Southern railway, just across the Nelson county line in Albemarle county, in the foot-hills of the Blue Ridge, and therefore in the crystalline schists of the Piedmont plateau. (Fig. 23.) The main developments comprise three shafts, sunk respec-

[4] *Bulletin No.* 1, *of the Virginia Geological Survey* (1905).

tively to depths of 25, 50 and 120 ft., and separated by a distance of about 1,000 ft. between the two extreme shafts. In addition to the three shafts, an adit-level was run into the hill from the valley bottom, and a cross-cut run from the adit, in and along the vein, for a distance of 140 ft., which extends beyond the middle and deep shaft. The map, Fig. 24, gives a plan of the mine and the plant.

The rocks in which the lead- and zinc-ores occur are metamorphosed crystalline schists, cut by a series of basic igneous dikes of diabase and diorite. Microscopic study indicates sev-



Scale, ½ inch = 1 mile. Contour Interval, 100 feet.

FIG. 23.—MAP OF LEAD- AND ZINC-DEPOSITS IN ALBEMARLE COUNTY, VA. BUCKINGHAM SHEET, U. S. G. S. Geology by Thomas L. Watson.

eral types of the schists which, in the outcrop, are easy of differentiation. These are thinly schistose, sericitic and chloritic schists, alternated or interbedded with a quartz-mica conglomerate schist. The sericite schist is quite garnetiferous, being filled in places with small, perfect crystals of red garnet. The chlorite schist is the ore-bearing rock. It is thinly fissile and thoroughly crinkled, the axes of the crinkling making an angle of about 90° with the planes of fissility. The rock contains little or no quartz and feldspar, but is largely composed of ferro-magnesian silicates. By the addition of quartz, this grades

into the conglomerate schist, which is composed of quartz, a little feldspar, and some mica, more or less altered to chlorite. The rock contains small fragments of granite, gneiss and schist, which are oriented in the direction of the schistosity, and are partly crushed and mashed from the effects of pressure.

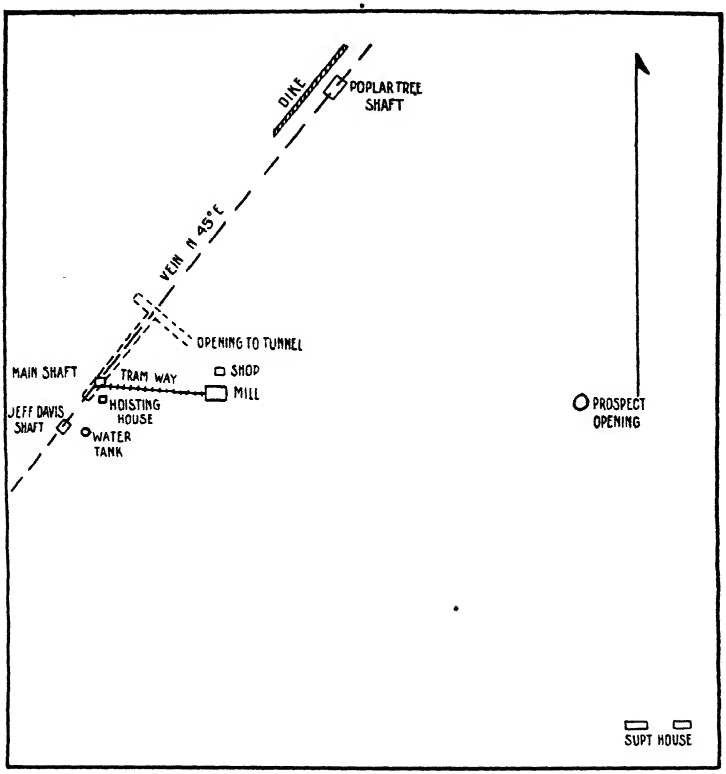


FIG. 24.—PLAN OF ALBEMARLE ZINC AND LEAD COMPANY'S MINE, NEAR FABER, ALBEMARLE COUNTY, VA.

The fragments are both angular and rounded. The rock is also cut in places by thin stringers of quartz and pegmatite.

The study of this series of rocks, both in the field and in the laboratory, leaves no doubt of its sedimentary origin. The strike is N. 45° to 50° E. and the dip is 70° to 85° NW. The exact age of these rocks is yet unknown, but they can probably be referred to pre-Cambrian.

At Faber's station, on the east side of the Southern railway,

the schists are cut by a large diabase dike, which is traceable for several miles in a N. from 5° to 10° E. direction. Under the microscope, thin sections of the rock from this dike show the typical diabase texture and normal composition. From this point eastward to the mine-openings, numerous intrusions of diorite are noted. One of the largest of the diorite dikes is exposed within 25 paces of the Poplar Tree shaft. These dikes have a trend of N. 45° E., and are parallel to the trend of the metalliferous vein. The rock composing the dikes shows considerable alteration of the minerals composing it. Hornblende and its common alteration-products, with quartz and some feldspar, comprise the mineral constituents. The diabase dike at the station is of the normal Mesozoic type; its substance is entirely fresh and unaltered, and it is probably younger than the diorite intrusions.

The metalliferous vein is reported to have been traced for a distance of several miles. It varies in width, averaging about 4 ft.; the strike is N. 45° E., exactly paralleling the diorite dike 25 ft. distant on the northwestern side; it dips from 80° to 85° NW. Where opened, it is of the lenticular type, composed of bulbous bodies of fluorspar mixed with some quartz, through which the ore, blende and galenite is distributed. The fluorite-quartz lenses vary much in size, and are often connected by a mere film of the same minerals, which, at other times, may be lacking altogether, thus, in such cases, giving the appearance to the vein of having given out. A marked banded structure is frequently indicated, particularly near the walls, which is due to included plates of the schist. These films or plates are often characterized by some impregnation of the ore. The relation of the fluorite-quartz lenses to the enclosing schists are shown in Fig. 25.

The ore, consisting of blende and galenite, occurs principally in the fluorite-quartz lenses, although the schists next to the lenses is often more or less mineralized. The blende and galenite may occur in separate bands and irregular masses distributed through the lenses; or they may occur intimately admixed in a single band or mass in the same lens. Fig. 26, which is a drawing of a large mass broken from one of the lenses, shows the typical occurrence. On working-out the ore, the two walls are entirely smooth and solid. Enough work has probably not

yet been done to indicate the true relations of the ores, blende and galenite; but, so far as developments extend, there seems to be some tendency in the galenite to follow or occur close to the foot-wall and the blende the hanging-wall. This relation may

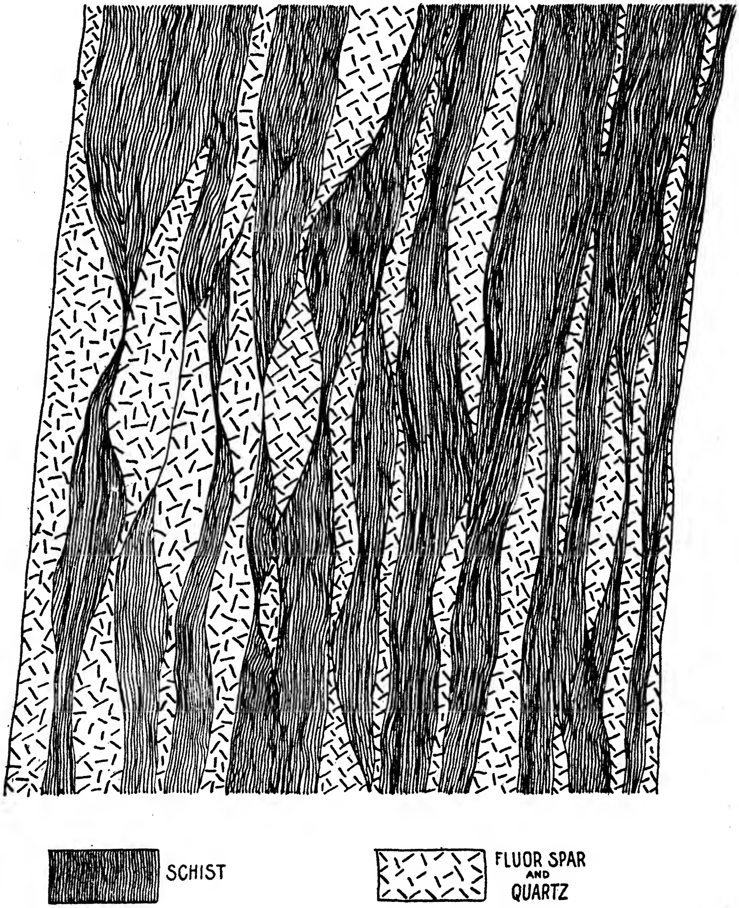


FIG. 25.—DIAGRAM ILLUSTRATING THE TYPE OF FISSURE-VEIN FORMED AT THE ALBEMARLE ZINC- AND LEAD-MINE, ALBEMARLE COUNTY, VA.

not continue on depth. It is the belief of the miners that the fluorite and blende increase in depth, and that the quartz and galenite decrease. Sufficient depth has not been reached, nor enough underground work done, to establish any relations of the ores to each other and to the gangue.

In addition to the principal ores, blende and galenite, some chalcopyrite occurs and some smithsonite. Some years ago, cerussite and azurite from the dumps were reported. The galenite is argentiferous, and arsenic and antimony are reported in very small quantities. Fluorite is the principal gangue-

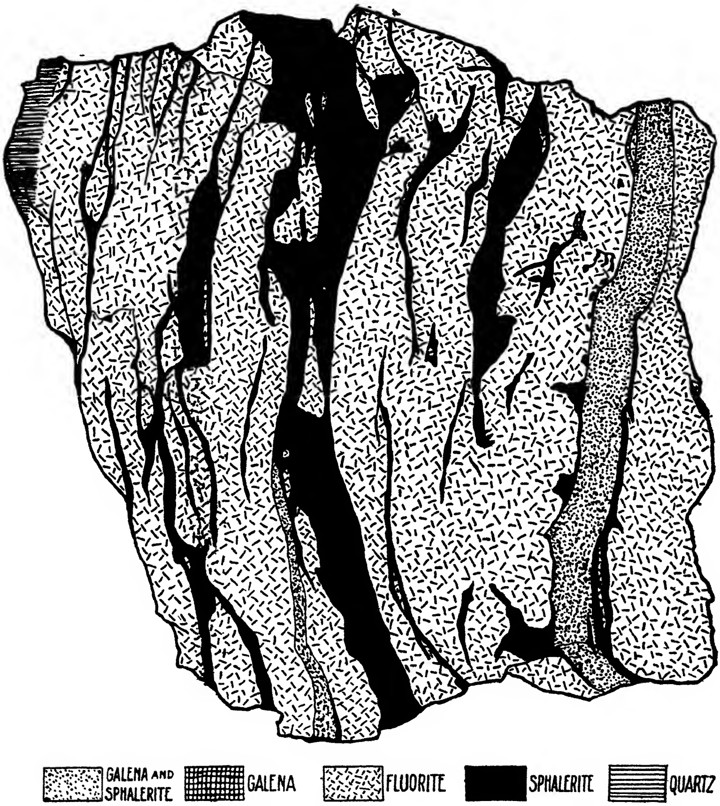


Fig. 26.—Specimen of Fluorite Lens, Showing Distribution of the Sulphide Minerals, Sphalerite and Galenite. Albemarle Zinc and Lead Company's Mine, Near Faber. About $\frac{1}{3}$ Natural Size.

mineral, with more or less quartz, and a little calcite and feldspar have been reported. The fluorite is mostly white, but quite a sprinkling of the violet shade occurs in places.

The very close association of the vein with dikes of igneous rocks makes it reasonably certain that the ores are genetically related to the igneous intrusions. The evidence of such rela-

tionship is strengthened when the composition of the gangue and the metals is considered. The principal and abundant gangue-mineral, fluorite, and the metallic sulphide, argentiferous galenite, with traces of arsenic and antimony, constitute an association of minerals such as can best be explained on the supposition of highly-heated conditions. Such could have been deposited only from waters of deep-seated origin, or from waters whose source of heat was derived from intruded igneous masses.

As to the age of the deposits, it can only be said that, in case the ores are genetically related to the dikes of igneous rock, they could not be older than the diorite dikes. These dikes are found, however, to be altered in every case, and are presumably older than the dike of diabase found east of Faber station, which can, without much doubt, be assigned to Mesozoic age. The deposits, therefore, could not be younger than the diabase intrusion, and are probably not older than the period of dioritic intrusion, the exact age of which has not yet been fixed.

The dry process for separating the ore is employed in milling. The problem is principally one of separating the blende from the fluorite, and of freeing the zinc-concentrates from lead, and the lead-concentrates from zinc. The ore is crushed and sized to pass a 16-mesh screen. All ore above this size is passed back to the rolls and crushed until properly sized. The ore thence goes to 4 rough jigs, and from here to 4 finishing-jigs. It is claimed that the tailings are practically freed from all ore by this process. If not, the jigs can be so regulated as to make a nearly complete separation. The important factor is that of the time involved in regulating and running the jigs. The trials so far made at the mill required the jigging-process to be repeated several times on the same ore before a clean concentrate could be obtained.

Through the kindness of Mr. Wikins U. Greene, Mining Engineer in charge of the plant, several bags of the lead- and zinc-concentrates were sent to me and were separately analyzed, giving the following results:

	Lead-Concentrates. Per Cent.	Zinc-Concentrates. Per Cent.
Lead,	63.05	6.02
Zinc,	12.12	47.88
Iron,	3.16	7.26
Copper,	trace	0.94
Sulphur,	19.32	29.52
Calcium fluoride,	1.31	4.74
Insoluble residue,	1.08	2.90
Total,	100.04	99.26

It is claimed from the tests made on the concentrates from this mill, that the following results represent fairly well the average composition:

Zinc concentrates: Zinc, 55 per cent.; lead, 4 per cent.	Copper about 0.05 per cent. Iron about 3 per cent.
Lead concentrates: Lead, 85 per cent.; zinc, 4 per cent.	

The dry process, employed at this plant for separating the ore, differs essentially from the wet process, in the form of jig used. The Krom jig, made of screens of different sizes of mesh, is used, substituting air for water. The jig can be set to yield 700 puffs of air per minute.

XVI. The Tennessee Deposits.[5]

1. *Introductory Statement.*

The principal lead- and zinc-deposits of Tennessee are grouped in two distinct belts; one lying near Powell river and the other near the Holston river. In the former, or Powell belt, ores of both lead and zinc occur, intimately associated, but varying widely in relative proportions. In the Holston belt lead-ores occur but sparingly.

While ores of the two metals have been found in nearly every county of the upper eastern Tennessee region, only a few of them had proved, until very recently, to be of economic importance. Mining in the past was confined largely to Mossy Creek, New Market, Straight Creek and Lead Mine Bend. Within the last 12 or 18 months active operations in deep mining have been in progress, confined chiefly to three dis-

[5] The Virginia deposits are described in considerable detail by me in *Bulletin No. 1, of the Virginia Geological Survey* (1905), hence they will not be repeated here.

tinct areas, namely, the Lead Mine Bend area in Union county; the Straight Creek area in Claiborne county; and the Holston River area in Knox and Jefferson counties. The greatest development-work has been in the Holston River area, which extends from 4 miles east of Knoxville for more than 20 miles northeastward, paralleling the Holston river and the Southern railway. Extensive drilling over most of the area has been in progress during the past 12 or 18 months. On the property of the Roseberry Zinc Co. drilling has exposed ore at a depth of 158 ft., and it extends to the extreme depth drilled, 202 ft. The ore is reported to average from 12 to 15 per cent. of metallic zinc, and it produces a concentrate containing more than 60 per cent. of zinc.[6]

2. *Description of the Mines.*

The most important mines in the East Tennessee region are here divided and discussed under three separate areas, namely, (1) the Lead Mine Bend area in Union county; (2) the Straight Creek area in Claiborne county; and (3) the Holston River area in Knox and Jefferson counties.

(a) *The Lead Mine Bend Area, Union County.*[7]—This area lies along and near Powell river, about 16 miles west of the Straight Creek mine, in Claiborne county. It has been extensively developed, and, as the name implies, it was originally worked for lead. Active prospecting is now in progress over the area. The ore-bearing area is a narrow zone, having a direction of N. 50° E., in which the rocks are crushed and broken; and it lies just south of the crest of the Powell anticline. At New Prospect the lead-ore is prominent, and the mineralized zone is traced for several miles northeast on both sides of the river. Lead- and zinc-ores are found, here and there, for a distance of 9 miles S. 70° W. of New Prospect.

The ore consists principally of galenite and blende, with smithsonite, calamine, cerussite, and a very little pyrite, with calcite. It occurs in the lower layers of the Knox dolomite.

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[6] *Engineering and Mining Journal*, vol. lxxx., No. 7, p. 311 (August 19, 1905).

[7] I did not visit this area; the information on it has been compiled from various sources, principally from the *Geologic Atlas of the United States, Maynardsville Folio, Tennessee, U. S. Geological Survey*, by Arthur Keith; and *Production and Properties of Zinc*, by W. R. Ingalls.

Smithsonite, calamine and cerussite occur near the surface in the limestone decay, and have been derived by weathering from the blende and galenite. Wide variation is shown in the relative proportions of blende and galenite. At New Prospect, galenite is the dominant ore, while, in other places in the area, blende forms the principal ore.

The ores are described as occurring in the crushed limestone, and in crevices which break the anticlinal fold longitudinally. The limestone is also mineralized for some distance on each side of the crevices.

Lack of transportation-facilities seems to have been the principal hindrance to the development of this area. The ore from the lead-mines was carted for a distance of 20 miles over a rough road, or else it was floated down the Powell and Clinch rivers on flat-boats to Clinton, where it was smelted.

(b) *The Straight Creek Area, Claiborne County.*—The principal mine in the Straight Creek area is located on Straight creek, about 5 miles SW. of New Tazewell, and about 3 miles west of Lone Mountain station, on the Knoxville and Cumberland (Southern) railway. It is reported to have been opened first about 25 years ago, and it has been worked since at intervals by several different companies. It is worked at present by the Tennessee Zinc Co. of Cincinnati, O.

The ores occur in the lower layers of the Knox dolomite, which, at this place, is a fine-grained and compact limestone, usually of dark color, and containing much organic matter in places. The beds strike N. 70° E. and dip from 35° to 45° SE., which increases to 60° in going eastward. The ore-bodies are located near a fault, and the rock is crushed and broken in places, forming a breccia in which the spaces between the fractures are smaller than in other places. The filling is largely composed of ore, with but little calcite and dolomite. Subsequent movement is indicated in numerous slickenside surfaces, coated with carbonaceous matter of some thickness, and, at times, with a thin film of pyrite.

The old workings comprise several pits, from 40 to 60 ft. deep, opened along the strike of the rock on top of the limestone ridge, and several hundred feet above the valley bottom. The ore mined comprised only the silicate and carbonate of zinc. Considerable lump iron-ore (limonite) is shown in the

dumps. Joints, approximately normal to the bedding-planes, are conspicuously developed in the limestone of the old openings. The ore is reported to have been traced along a NE–SW. direction for a distance of about 4 miles, and recent prospect-openings that promise well have been made on Birch creek, about 2 miles west of the present mines.

Recent work at the mines comprises a single tunnel driven into the ridge from near the valley bottom in a northerly direction for a distance of about 700 ft., and at a depth of about 150 ft. below the surface. Stoping at this point developed an ore-body about 40 by 60 ft. in the direction of the strike, and at right angles to the axis of the tunnel. The dip of the ore-body (ore-shoot) is toward the east, and it pinches in the same direction. So far as developments extend at this locality, the ore-bodies in general indicate both eastward dip and pinching; and they divide or split at the west end.

In the early mining much soft ore, mostly silicate, was removed; but within recent years mining has been confined to the sulphide ores. Blende, some galenite, and in places much pyrite, make up the sulphide ores. These are intimately associated, and contemporaneous deposition is indicated. In places alternating bands of the sulphide ores were observed. Usually the pyrite and galenite are more or less distributed through, or enclosed by, the blende, though each may occur separately, as is often the case. The blende is fine granular, gray in color, and is disseminated. Pyrite may occur in masses measuring as much as a foot or more in diameter; or as stringers, filling the fractures and cementing the broken rock-fragments forming breccia; or in association with the blende and galenite.

Very small stringers or veinlets of blende, less than an inch in width, may fill the rock-fractures or cracks, gradually becoming larger and larger until the rock substance is very largely or entirely replaced by the ore. This replacement process is illustrated in Figs. 27 and 28. A very striking feature at these mines is the extensive scale on which replacement of the rock substance by the sulphide ores has taken place. Very little white calcite or dolomite occurs, though this may be due, in part at least, to the calcite or dolomite being impure and discolored by iron or other impurities, as is undoubtedly true in places. The small amount of white calcite or dolomite ob-

served was present in the form of the thinnest films, cementing the broken rock-fragments together. Barite, fluorite and quartz

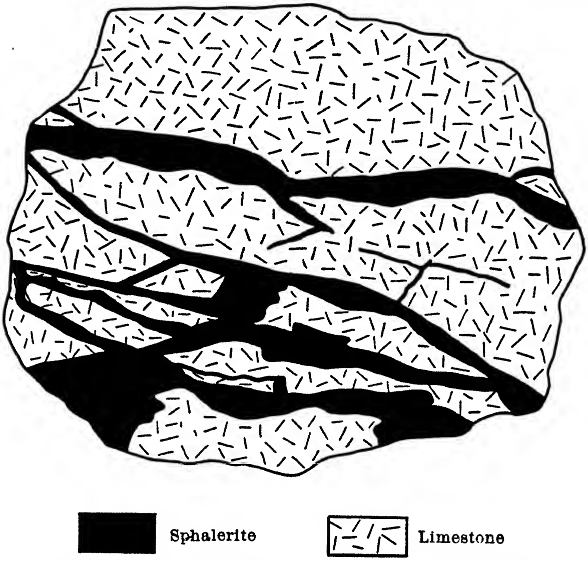

FIG. 27.—ORE SHOWING REPLACEMENT OF LIMESTONE BY BLENDE. STRAIGHT CREEK ZINC-MINE, CLAIBORNE COUNTY, TENN.

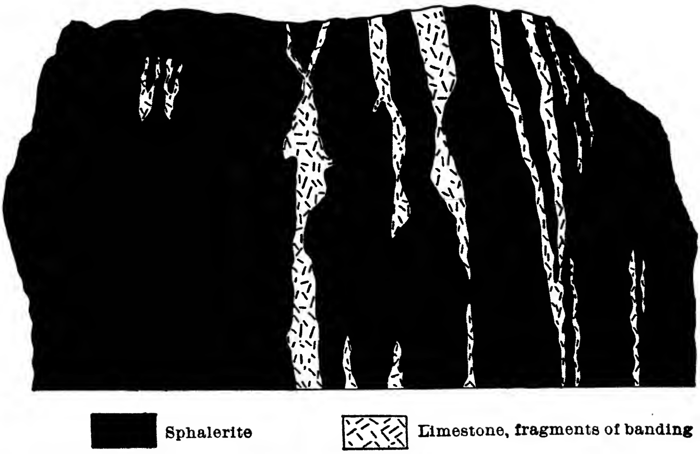

FIG. 28.—ORE FROM THE STRAIGHT CREEK MINES, SHOWING REPLACEMENT OF LIMESTONE ALONG BANDING BY SPHALERITE. CLAIBORNE COUNTY, TENN.

do not occur. Fig. 29 illustrates the replacement breccia ore, showing limestone with blende and galenite.

As is stated above, the rock in the mine-openings bears striking evidence of its being more highly carbonaceous than elsewhere,—a fact which probably indicates that the solutions contained the metals as sulphates; that they were introduced as such, and were reduced and precipitated as sulphides. Filling by the ores was first along the fracture- and bedding- planes extending gradually out and into the rock substance on each side by a process of replacement. Considerable oxidation is

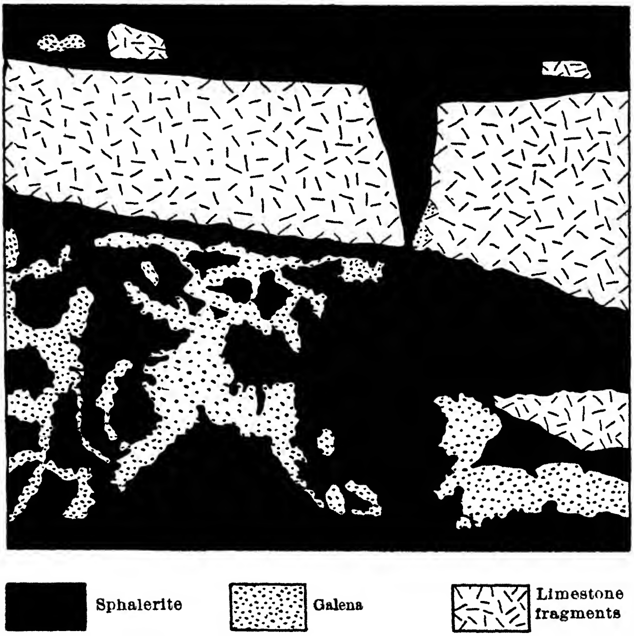

FIG. 29.—REPLACEMENT BRECCIA ORE, SHOWING LIMESTONE WITH BLENDE AND GALENITE. STRAIGHT CREEK MINES, 5 MILES SOUTHWEST OF NEW TAZEWELL, CLAIBORNE COUNTY, TENN.

manifested to the entire depth of stoping, 150 ft., in large clay-seams, which fill the fractures, and some associated secondary soft ores.

A mill, fitted with crusher, rolls and hand-jigs, was formerly operated at the mines, but at the time of my visit, in April, 1905, preparations were being made to install a commodious and modern mill. The ore as mined is cobbed to a yield of about 45 per cent. of zinc; and it will probably concentrate in milling to an average of not less than 52 per cent. of zinc. The

amount of iron present will, as a rule, probably not cause much trouble, and, by fine crushing and jigging, much of the lime can be eliminated. Probably the chief trouble is the question of transportation. Carting over a rough road for a distance of 6 miles is necessary at present. The nearest railroad point can be reached at a distance of about 4.5 miles.

Very recently prospecting near Goin Post Office, on Sugar and Slate creeks, in Claiborne county, and from 6 to 7 miles west of Tazewell, has exposed deposits of intimately associated blende and galena.

If we compare the occurrence of zinc-ore in Tennessee and Virginia, so far as developments have been made, it is only at the Straight Creek mine in Claiborne county, Tenn., and the Austinville mine in Wythe county, Va., that well-defined ore-bodies have been noted. In other parts of the district the ore is of the typical disseminated breccia type, in which replacement has played only a subordinate part.

The principal points of resemblance in the occurrence, association and genesis of the ore at these two mines are: (1) the presence of well-defined ore-shoots; (2) the intimate association of galenite and blende with subordinate pyrite; (3) similarity in the process of formation in the ore-bodies to the extent of first forming along the intersection of the joint- and bedding-planes; (4) the extensive replacement of the limestone substance by the sulphide ores. At each one of these mines the process of ore-formation was largely one of replacement.

The essential points in which the two differ are: (1) the rock (limestone) in the Tennessee mine is not so metamorphosed (re-crystallized) as in the Virginia mine, and less secondary calcite and dolomite occurs in the former mine; (2) the presence of considerable organic matter in the limestone at the Straight Creek mine, and its essential absence at the Austinville mine; (3) the probable introduction of the metals in the form of the sulphates in the Tennessee mine; their reduction by the organic matter present in the limestone and deposition as the sulphides. It seems equally probable that at the Austinville mine the metals were introduced as soluble sulphides, and were deposited as such. In other words, these two mines probably illustrate two different chemical cycles; one the sulphate cycle;

the other the sulphide cycle. This difference probably exists for the district as a whole, as in most cases the field-evidence seemingly favors the introduction and deposition of the ores in the form of original sulphides, while in several places in Virginia the very close relation of the ores, with certain layers of the limestone containing organic matter, favored the introduction of the ores in the form of sulphates, and their reduction by the organic matter and deposition as sulphides.

(c) *The Holston River Area, Knox and Jefferson Counties.*—The greatest development-work in the Tennessee district has probably been done in the Holston River area, which extends from 4 miles east of Knoxville for more than 20 miles northeastward, paralleling the Holston river and the Southern railway. Considerable prospecting, in the form of drilling, is now in progress over most of the area. The principal mines in this area, that were formerly worked, or are at present working, are grouped near the following stations on the Southern railway: Jefferson City (Mossy Creek), New Market, Mascot, McMillan and Caswell, with some prospecting on Loves creek, 5 miles northeast of Knoxville. These are taken up in their order and described in some detail below.

(d) *Jefferson City* (*Mossy Creek*).—The Mossy creek zinc-mines are located on the southeast edge of Jefferson City, directly on the east side of Mossy creek, and about 500 ft. southeast of the Southern railway. These mines mark the first discovery of zinc-ores in Tennessee, during the period from 1856 to 1858. The first mining of the ores is reported to have been in the year 1868, but systematic mining did not begin until 1881, and was continued until 1893. Work was again resumed for one year in 1901.

The workings comprised open cuts and pits, tunnels and shafts, from which a very large quantity of ore was mined. At the time of my visit, in April, 1905, the mine-openings were largely filled with water, and were only partly accessible. The greatest depth reached in mining is reported not to have exceeded 90 ft. During the period of early mining, the production in soft ores of great purity, carbonate and silicate, was considerable. The residual decay, red clay, which covered the soft ores, was not so deep, nor was the underlying limestone surface of the pinnacle or "chimney" structure, as at the Ber-

tha and Austinville mines in Virginia. At present the mine-openings at Mossy creek do not expose greater depths of the residual clay than 30 ft., and, as a rule, much less.

The country-rock is the characteristic Knox dolomite, light gray in color, of semi-crystalline texture, and contains nodules and masses of chert. In the open-work at the mines the rock has been profoundly crushed and broken, and the fragments cemented by white crystallized calcite and dolomite. In large masses the calcite-dolomite filling develops the typical rhombohedral cleavage. An analysis made of the calcite part of the filling or cement gave the following results:

	Per Cent.
Calcium carbonate ($CaCO_3$),	93.71
Magnesium carbonate ($MgCO_3$),	0.84
Ferric oxide Fe_2O_3, Alumina Al_2O_3,	0.22
Insoluble residue,	6.08
Total,	100.85

Blende is the ore in the unaltered limestone. Neither galenite nor pyrite was observed. The blende is usually yellow in color, and its principal occurrence is in disseminated form through the calcite-dolomite filling of the limestone breccia. At times, more or less replacement of the limestone fragments by the blende is indicated, and not infrequently the fragments are partially rimmed by the blende. This relation of the ore to the calcite-dolomite filling and to the limestone fragments, shown in Figs. 10, 11 and 16, indicate that the ore is of the disseminated breccia type. It is confined to the breccia-zone, which has a nearly N–S. direction, and marks the plane of a large fault.

A mill was formerly operated at the mines, but it has been dismantled since mining was suspended.

(e) *New Market.*—The Ingalls mine, located on Lost creek, about 2 miles southeast of New Market, has produced large quantities of ore. Considerable work has been done, comprising several large open pits or quarries extending some depth into the hard and unaltered limestone. The limestone is the Knox dolomite of the same general character as described above at the Mossy Creek mine. The beds are rather flatter here than at some of the mines further southwest, showing an

average dip of about 20° SE., and strike N. 65° E., which develops a small anticline at this point. The strata have been broken and the fragments recemented by white crystallized calcite and dolomite. It is along this breccia-zone, which here averages probably not more than 50 ft. wide, that the ores have been localized and deposited. In occurrence the ore is quite similar to that at Mossy creek, and it is of the same type. At both places the indications are that the sulphide ore was introduced and deposited simultaneously with the calcite-dolomite filling, cementing the limestone fragments.

The ores comprised carbonate and silicate forms in the oxidized zone, and yellow blende in the unaltered limestone. A little pyrite occurs, but galenite is essentially absent. Ingalls[8] records the following analyses of ores from this mine:

Smithsonite	Per Cent	Sphalerite	Per Cent.
$ZnCO_3$,	83 29	ZnS,	84.75
SiO_2,	13.10	SiO_2,	7.57
$FeCO_3$,	1.32	Fe_2O_3 } Al_2O_3 },	1 66
Fe_2O_3,	0.66		
$CaCO_3$,	1.07	$CaCO_3$,	5.98
$MgCO_3$,	0.56	$MgCO_3$,	0 04

(f) *Loy.*—The mines, located about one mile slightly south of east from New Market, comprise two sets of openings, worked at different times, and separated from each other by a distance of less than one-quarter of a mile along a NE–SW. direction. The easternmost openings were worked for a period of from 12 to 15 months about 1892, when much calamine and smithsonite were reported to have been mined and shipped to Marion, Ind. The depth reached in mining extended for some distance into the fresh limestone, but did not exceed a total of 50 ft. The openings are made in a breccia-zone, and the fresh rock shows yellow blende of similar character and occurrence to that described above at the Ingalls and Mossy Creek mines, but probably leaner. Neither galenite nor pyrite was noted.

The westernmost openings are made in the residual clays mantling the limestone, for mining the soft ores. Work was begun about 15 months ago, and was in progress at the time of my visit, in April, 1905. About half a dozen cars of soft

[8] *Production and Properties of Zinc*, p 198 (1902).

ores, carbonate and silicate, principally the latter, had been shipped to the Bertha furnaces at Pulaski, Va. Average returns from the last car of ore gave 44.20 per cent. of zinc. The thickness of the residual mantle will not exceed 40 ft., but the conditions seemingly favor a rather large area of concentrated soft ores, derived, in the usual way, by weathering from the sulphide, sphalerite.

About two miles southwest of New Market, near Friend's Station, recent prospecting indicates the presence of blende in the magnesian limestone.

(g) *Mascot.*—The property of the Roseberry Zinc Co. is located about one mile west of Mascot, between Roseberry creek and the Holston river. For about a year this company has been constantly drilling its property, with encouraging results. At the time of my visit, in April, the work comprised one large opening, a number of small openings, and a shaft which had reached a depth of 116 ft., penetrating 30 ft. of residual clay and the remaining depth of brecciated limestone. Ore was found at a depth of 104 ft. The shaft has been continued to a depth of 172 ft., drifting on a 14-ft. face of ore, which averages from 12 to 15 per cent. of zinc, and producing a concentrate of about 60 per cent. of zinc.[9]

The large opening, which was worked to some depth in the limestone, exposes a typical breccia of the same character described above. Blende is the ore, and it is associated with the calcite-dolomite filling or cement; disseminated through it, as a rule, in fine granular form, and in irregular small crystalline masses. Galenite seems not to occur, but quite a sprinkling of pyrite is found in places. A common occurrence of the ore and calcite-dolomite is in the filling of cracks in the crushed limestone. As a rule, replacement is only slightly indicated. Large quantities of soft ores are reported to have been mined some years back.

The dip of the limestone beds varies, giving a probable average of 20° SE., with much steeper inclinations noted in places; strike N. 35° E. At one point a crust or druse of small gypsum crystals was noted.

A commodious mill, equipped with the necessary jigs, breakers, rolls and tables, is in operation. The ore is free from such

[9] *Engineering and Mining Journ.*, vol. lxxx., No. 7, p 311 (August 19, 1905).

impurities as barite, pyrite and fluorite, which at times are sources of much trouble in some ores, but its fine-grained disseminated character requires fine crushing and very careful milling with jigs and tables, in order to free it from the limestone and give a clean concentrate.

(h) *McMillan, Caswell and Loves Creek.*—Less than half a mile north of McMillan some open work and drilling have recently been done, exposing yellow blende in a brecciated dolomite, similar to the occurrences described above. Galenite and pyrite do not occur. Measurements of the limestone beds gave an average dip of 25° SE. and a strike of N. 45° E.

Drilling was in progress in April about half a mile northeast of Caswell with reported favorable indications.

About 5 miles northeast of Knoxville, on the north side of the Southern railway, and on both sides of Loves creek, some open work has recently been done. Here the dolomite is brecciated, and it contains thin masses or leaves of greenish shales that are much crushed. Considerable chert is contained in the limestone, and, in several instances, blende in association with the chert was observed to be partly altered to calamine. Galenite and pyrite are absent. The limestone beds show a strike of N. 65° E. and dip from 30° to 35° SE.

(i) *Other Localities.*—In Blount county, across the Tennessee river and south of Knoxville; and in Bradley county, from 20 to 30 miles east of Chattanooga, galenite is found in a number of places in sufficient quantity to make mining profitable. Mining and prospecting, where galenite is found in these counties, indicate that the ore is disseminated through the Cambro-Ordovician limestone (Knox dolomite). In Bradley county the ore occurs most abundantly near the base of the Knox dolomite, and in the heavy blue limestone at the top of the Conasauga shale (Cambrian). For some years galenite has been mined and smelted at Blue Springs, a station on the Southern railway, about 6 miles south of Cleveland. Similar conditions to those at Blue Springs are found in many places over the area, and doubtless future prospecting will reveal valuable deposits.

Recently, prospecting has been quite active over a considerable part of Blount county, and in many places the results are very encouraging. The Valley Mount Lead Co. has done con-

siderable work in the way of cuts, tunnels, etc., and is now preparing to drill its property. The occurrence of the ore is reported to be similar to that of southeastern Missouri, but it carries a higher percentage of lead than the latter. At the Cedar Ridge mine, where some work in the form of cuts and shafts has been done, the indications are that drilling will probably prove the property to be a valuable one. Prospecting, sufficient only, as a rule, to indicate the presence of lead-ore, has been carried on at several points in the county, principally along and near the Louisville and Nashville railway.

XVII. General Conclusions Regarding the Ores.

From the previous description and discussion the following conclusions seem to be warranted:

1. The zinc- and lead-ores of the Great Valley region of Virginia-Tennessee were originally deposited with the limestone in which they were subsequently localized and concentrated and are now found. Unlike the deposits of this district, the one in Albemarle county, Va., occurs in crystalline schists, and was probably genetically connected with igneous intrusions.

2. The district is one of intense deformation,—folding, faulting and brecciation. The ores are closely associated with the faulting and folding, and are of the disseminated replacement breccia type.

3. The accumulation and concentration of the ores as they are now found were by circulating underground waters. These were probably transported in the form of both sulphates and sulphides; and they were precipitated and deposited in their present position partly by organic matter and partly by the mingling of solutions and the reaction of the ore-bearing solutions on the wall-rock, limestone.

4. From the character of the metallic sulphides and the associated minerals, neither a profoundly deep circulation of underground waters nor of a circulation connected with igneous rock-masses, was responsible for the deposition of the ores.

5. The associated minerals of the non-metallic type include dolomite and calcite in crystalline form as the principal ones, with a little fluorite, quartz and barite found in several places in the Virginia area.

6. Replacement has been an important process in the for-

mation of the ores over a part of the district. The common evidences of sulphide enrichment are lacking, and the sulphide ores are regarded as the products of a first or primary concentration.

7. The soft or oxidized ores, carbonates and silicates, were produced by the alteration of the original sulphide ores, galenite and sphalerite, in the zone of oxidation.

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DISCUSSIONS.

Comparison of Methods for the Determination of Carbon and Phosphorus in Steel.

Continued Discussion of the Paper of Messrs. von Jonstorff, Blair, Dillner and Stead, presented at the New York Meeting of the Iron and Steel Institute, October, 1904.*

CLEMENS C. JONES, Richmond, Va. (communication to the Secretary†):—In the chapter of this paper entitled "Method for the Determination of Phosphorus," by Andrew A. Blair, a form of the reductor used by Mr. Blair is illustrated. This form was employed by me in my earliest experiments, and abandoned after my adoption of the final apparatus described in my paper[1] on the subject in 1889. The results reported by Mr. Blair are very closely accordant; but my experience was that, in the use of this form, a loss of the solution, amounting to almost a cubic centimeter, was occasioned by minute bubbles of hydrogen rising to the surface, and there exploding. My final reductor was designed to prevent this loss; and the most satisfactory results were obtained with a reductor having the open cup replaced by a bulb-shaped receptacle, provided with a glass stopper, similar to that of a separatory funnel of similar capacity, as suggested in a foot-note in my original paper. In my experience, the use of this later form of reductor repeatedly gave duplicate results which were coincident to the fourth decimal place.

R. W. RAYMOND, New York, N. Y.:—The remarks of Mr. Jones recall to my mind an interesting part of the history of the Institute, and of its relation to modern progress in the department covered by this interesting and valuable paper. In my Biographical Notice of the late Thomas M. Drown,[2] I have

* Published, by mutual agreement between the Councils of the two Institutes, in the *Bi-Monthly Bulletin* of this Institute for March, 1905, pp. 289 to 335, but not in the annual volume of the *Transactions*. See, also, in the *Bi-Monthly Bulletin* for May, 1905, pp. 642 to 645, a discussion by R. Hamilton and others.

† Received February 6, 1906.

[1] *Trans.*, xvii., 413.

[2] See p. 288.

emphasized his leadership, and his powerful influence, through personal investigations and publications, and through the inspiring example and guidance given to his pupils, in promoting the employment of chemists by manufacturers, and (as a means to that end) in perfecting the methods and apparatus for simple, rapid and accurate commercial analyses. The volumes of our *Transactions*, in their "Symposiums" and other comparisons and discussions of analytical laboratory-methods, bear witness to the profoundly important and extensive results of the movement in which he took so influential a part; and in no other field is this more impressively shown than in that of the chemical analysis of iron-ore, iron and steel.

In 1878, Dr. Drown published a paper[3] on the uses of pulverized zinc as a precipitant in the laboratory. Like many other stimulating suggestions made by him, this was taken up in practice by his pupils and others, who were at that time beginning to be employed at manufacturing establishments previously accustomed to "get along" without chemical laboratories of their own. One of the earliest companies to adopt this policy was the Thomas Iron Co., which set up a laboratory at Hokendauqua, Pa., and employed as chemist Mr. Clemens C. Jones. Mr. Jones soon made himself known by novel and ingenious investigations and experiments, of which, for my present purpose, I need mention only two, which are recorded in our *Transactions*.

At the New York meeting of the Institute, in February, 1889, Mr. Jones presented his paper on "A Rapid Method for the Reduction of Ferric Sulphate in Volumetric Analysis," in which a new method of employing pulverized zinc as a precipitant was described and illustrated. It goes without saying that Drown's suggestion, made eleven years earlier, had not passed through that period without attention. Indeed, at a meeting of the Chemical Society at London, April 5, 1888, a paper was read by Mr. D. J. Carnegie on "The Action of Finely-Divided Metals on Solutions of Ferric Salts, and a Rapid Method for the Titration of the Latter."[4] In the discussion of this paper, the author acknowledged that the use of

[3] *Trans.*, vi., 508.

[4] *Chemical News*, vol. lvii., No 1481, April 13, 1888, p. 148.

powdered zinc had been suggested "some years ago" by Drown. (The *Chemical News* printed it *Brown*—such is earthly fame!)

But neither Dr. Drown nor Mr. Carnegie nor anybody else, so far as I can find out, proposed the one thing required to remove the practical objections to this use of zinc. The latest practice, as set forth by Carnegie, was to put zinc-dust into the solution under treatment, and "shake" it. In the following year, Mr. Jones not only proved experimentally, but designed an apparatus for utilizing in practice, the fact that "a solution of ferric sulphate is instantaneously and completely reduced by filtering through pulverized zinc,"[5] and thus made the method practicable, by removing certain difficulties attending its use, which I need not here pause to discuss, since they are sufficiently set forth in the publications already cited.

The apparatus designed by Mr. Jones for this operation he called a "reductor." I have always understood that the name, as well as the thing, originated with him; and I remember that Dr. Drown agreed with me in regarding it as a most important contribution to practice in the rapid and accurate analysis of iron-ore, iron and steel. In his contribution to the present discussion, Mr. Jones has given reasons for his opinion that the form of reductor used by Mr. Blair is inferior to the form which he himself finally preferred, after trying both. But he has modestly refrained from asserting his claim as the originator of this apparatus, and of its use in the laboratory. In a subsequent paper,[6] Mr. Jones pointed out that the method and apparatus introduced by him for reducing ferric solution, with the aid of his reductor, applied "in all respects equally well to the complete and instantaneous reduction of molybdic acid."

The later paper of Mr. Jones, last cited, was presented at the Washington meeting of February, 1890, under the title, "Phosphorus in Pig-Iron, Steel and Iron-Ore." Under that head the previously-suggested methods of analysis were discussed, and a procedure based upon extensive laboratory-experiments was recommended. If I am not mistaken, this method is essentially the one described in the paper before me, as adopted by Mr. Blair.

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[5] *Trans*, xvii., 413.

[6] *Trans.*, xviii., 709.

Mr. Jones offered other suggestions in the line of laboratory-methods, which, taken together with those I have mentioned, entitle him, in my opinion, to recognition among those acute investigators and practitioners who have brought about a distinct revolution and reconstruction of modern practice. It is to be regretted, from my present standpoint, that he did not continue in the special work which he so brilliantly began, but was diverted into other professional and business fields.

In thus recalling his early contributions, I wish to say that I do not by any means blame the authors of this paper for omitting to mention his name. It would be absurdly unreasonable to require, in an up-to-date treatise, the specific recognition of all previous contributions to the progress which it summarizes. Possibly it might be urged that the "Jones reductor" has as good a claim to individuality as the Erlenmeyer flask, the Griffin beaker, the Liebig bulb, or the Bunsen burner. But I have no desire to criticise, in such a treatise as this, the mere omission of a name. I do not find fault with the *omission*; I wish only, in justice to the Institute and one of its members, to complete the record by supplying the *name*.

As Secretary of the Institute, and Editor of its *Transactions* for 22 years past, I may be pardoned for some jealousy concerning its fame, as the channel through which important discoveries and improvements, in the numerous branches of science and practice represented by its membership, have been first made known. This feeling is my excuse for the foregoing remarks.

The Application of Dry-Air Blast to the Manufacture of Iron.

A Discussion of the paper of James Gayley (see *Trans.*, xxxv., 746, 1022), also p. 315 of the present volume.

JOSEPH W. RICHARDS, South Bethlehem, Pa. (communication to the Secretary*): The bold experiment of Mr. James Gayley in drying the blast used in the Isabella furnace has attracted the attention of the whole metallurgical world, and has given rise to a wide discussion of the reasons for its great success. Mr. Gayley and the capitalists who backed him in his work deserve congratulations on the success of the venture, not only because it succeeded, but because they have been rewarded far beyond the maximum that could be expected from theory or probability.

To state the case in its simplest terms, all that could have been predicted was: (1) that the removal of the moisture from the blast would result in the saving of the heat required for its decomposition, representing from 3 to 5 per cent. of the heat-value of the coke used; hence about that quantity of fuel might be saved; (2) that the furnace would be somewhat more independent of variations in the weather; (3) that the campaign would be a little hotter; and (4) that the speed of the blowing-engines would be decreased, at least in amount proportionate to the reduction in temperature of the air led to them. I do not think anyone anticipated a much larger output per day.

The results actually attained were: (1) the furnace made an increase of 24.86 per cent. in the output of pig-iron per day; (2) it consumed 19.6 per cent. less coke per ton of pig-iron made; (3) the blowing-engines were run 15.8 per cent. slower; and (4) the saving in power made up for the power required to run the refrigerating-plant. In addition, the blast was hotter; the waste-gases cooler, because of their smaller volume; and there was a greater proportion of carbon dioxide to carbon

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* Received March 27, 1905

monoxide in the waste-gases, showing a better utilization of the carbon in the furnace.

The object of the present discussion is to contrast the working of the furnace both with and without dry-air blast, by means of calculations from the data available, thus finding the true items of the great and unexpected economy obtained by Mr. Gayley.

TABLE I.—*Data of Blast-Furnace Operations.*

	Moist-Air Blast	Dry-Air Blast.
Charge consisted of :—Coke, pounds	10,200	10,200
Ore, pounds	20,000	24,000
Stone, pounds	5,000	6,000
Pig-iron produced per day { tons	358	447
Pig-iron produced per day { pounds	801,920	1,001,280
Coke used per day, pounds	768,626	771,522
Speed of blowing-engines, rev. per min	114	96
Horse-power of blowing-engines, indicated	2,700	2,013
Temperature of air in engine { F°	75	25
Temperature of air in engine { C°	24	—4
Piston-displacement stated, cu. ft. per min	40,000	34,000
Temperature of blast at furnace { F°	720	870
Temperature of blast at furnace { C°	382	465
Temperature of waste-gases { F°	538	376
Temperature of waste-gases { C°	281	191
Composition of waste-gases { CO_2 per cent.	13	16
Composition of waste-gases { CO per cent.	22.3	19.9

The furnace had four stoves, twelve 6-in. tuyeres; the blowing-cylinders were 84 in. in diameter and of 60-in. stroke. The furnace made pig-iron containing less than 1 per cent. of silicon; the ore-charge was half Mesabi and half soft Michigan hematites, averaging 53.5 per cent. of iron in the mixture; the coke contained from 10.5 to 12.5 per cent. of ash.

In order to complete the balance-sheets, it was assumed that the ore contained, H_2O, 10; SiO_2, 10; Al_2O_3, 3.5 per cent. The limestone, SiO_2, 5; MgO, 4.8; CaO, 47.6; and CO_2, 42.6 per cent. The coke, SiO_2, 5.3; CaO, 5.3; H_2O, 1; and fixed carbon 88 per cent. The pig-iron, Si, 1; C, 4; and Fe, 95 per cent.

While the conditions assumed may not correspond exactly with those of the actual furnace-practice, they are sufficiently close not to disturb the general conclusions to be drawn from this discussion.

From the data supplied and assumed, the balance-sheet of the materials entering and leaving the furnace, per 100 parts of pig-iron produced, is constructed as given in Tables II. and III.

TABLE II.—*Balance-Sheet per* 100 *Parts of Iron Produced. Moist Blast.*

Charges.		Pig Iron.	Slag	Gases.
Ore, 177.6.	Fe_2O_3, 135.7	Fe, 95.0		O, 40.7
	H_2O, 17.8			H_2O, 17.8
	SiO_2, 17.8	Si, 1.0	SiO_2, 15 7	O, 1.1
	Al_2O_3, 6.3		Al_2O_3, 6.3	
Flux, 44.4	SiO_2, 2.2		SiO_2, 2.2	
	CaO, 21.1		CaO, 21.1	
	MgO, 2.1		MgO, 2.1	
	CO_2, 19.0			CO_2, 19 0
Fuel, 95.8.	C, 84.3	C, 4.0		C, 80 3
	SiO_2, 5.3		SiO_2, 5.3	
	CaO, 5.3		CaO, 5.3	
	H_2O, 0.9			H_2O, 0.9
Blast, 422.2	O, 96.4			O, 96.4
	N, 321.3			N, 321.3
	H_2O, 4 5			H, 0.5; O, 4.0
Total.	740.0	100 0	58.0	582.0

TABLE III.—*Balance-Sheet per* 100 *Parts of Pig-Iron Produced. Dried Blast.*

Charges.		Pig-Iron	Slag.	Gases
Ore, 177.6.	Fe_2O_3, 135.7	Fe, 95.0		O, 40.7
	H_2O, 17.8			H_2O, 17.8
	SiO_2, 17.8	Si, 1.0	SiO_2, 15.7	O, 1.1
	Al_2O_3, 6.3		Al_2O_3, 6.3	
Flux, 44.4.	SiO_2, 2.2		SiO_2, 2.2	
	CaO, 21.1		CaO, 21.1	
	MgO, 2.1		MgO, 2.1	
	CO_2, 19.0			CO_2, 19.0
Fuel, 77.0.	C, 67.8	C, 4 0		C, 63 8
	SiO_2, 4.2		SiO_2, 4.2	
	CaO, 4.2		CaO, 4.2	
	H_2O, 0 8			H_2O, 0.8
Blast, 332.5.	O, 76 5			O, 76.5
	N, 255.0			N, 255.0
	H_2O, 1 0			H, 0.1; O, 0.9
Total...	...631.5	100 0	55.8	475.7

Table IV. gives the details of the calculations necessary for the calculation of the balance-sheet of Tables II. and III. The heat-balance sheet is given in Table V. and the details of its calculation in Table VI.

TABLE IV.—*Details of Calculations (per 100 Kg. of Pig-Iron) Used for Tables II. and III.*

Volume of Waste-Gas: *Moist Blast.*

Carbon in gases $= 80\ 3 + (\frac{3}{11} \times 19) = 80.3 + 5.2 =$	85 5	kg.
Carbon in 1 cu. meter of gas $= (13 + 22.3) \times 0.54 =$	0 19062	kg
Gases produced per 100 parts of pig-iron $= \frac{85.5}{0.19062} =$	448 5	cu meters.

Dried Blast

Carbon in gases $= 63.8 + (\frac{3}{11} \times 19) = 63\ 8 + 5.2 =$	69.0	kg.
Carbon in 1 cu. meter of gas $= (16 + 19.9) \times 0\ 54 =$	0 19386	kg.
Gases produced per 100 parts of pig-iron $= \frac{69.0}{0\ 19386} =$	355.9	cu meters.

Oxygen in Blast: *Moist Blast.*

Oxygen in 1 cu. meter of gas $= \left(13 + \frac{22\ 3}{2}\right) \times 1.44 =$	0.34776	kg
Oxygen in total gases $= 0\ 34776 \times 448.5$	$=$ 156	kg.
Oxygen from solid charges (exclusive of water)	$=$ 55.6	kg.
Oxygen from the blast $= (156 - 55.6)$	$=$ 100.4	kg

Dried Blast.

Oxygen in 1 cu meter of gas $= \left(16 + \frac{19.9}{2}\right) \times 1.44 =$	0.37368	kg.
Oxygen in total gases $= 0.37368 \times 355.9$	$=$ 133	kg.
Oxygen from solid charges (exclusive of water)	$=$ 55.6	kg.
Oxygen from the blast $= (133 - 55.6)$	$=$ 77.4	kg.

Combustion of Carbon. *Moist Blast.*

Carbon burnt at the tuyeres $= 100.4 \times \frac{3}{4}$	$=$ 75.3	kg
Carbon burnt above the tuyeres $(80.3 - 75\ 3)$	$=$ 5 0	kg
Proportion of fixed carbon burnt at the tuyeres	$=$ 89.3	per cent.

Dried Blast.

Carbon burnt at the tuyeres $= 77.4 \times \frac{3}{4}$	$=$ 58.05	kg.
Carbon burnt above the tuyeres $= 63.8 - 58.05$	$=$ 5.75	kg.
Proportion of fixed carbon burnt at the tuyeres	$=$ 85.6	per cent.

Moisture and Air in Blast: *Moist Blast.*

Water per cu. ft. of air $= \frac{5.66 \text{ grains}}{437.5}$	$=$ 0.013	oz.
Water per cu. meter of air at 24° C.	$=$ 0.013	kg.

Water per cu. meter of air at 0° C.	=	0.014	kg.
Oxygen in this moisture	=	0.0126	kg.
Oxygen in 1 cu. meter of dry air at 0° C.	=	0.2984	kg.
Total oxygen per cu. meter of dry air at 0° C.	=	0.3110	kg.
Volume of dry air used $= \frac{100.4}{0.311}$	=	322 8	cu. meters.
Weight of oxygen present as air	=	96.3	kg.
Weight of nitrogen present	=	321.0	kg.
Weight of moisture present $= 322.8 \times 0.014$	=	4.52	kg.

Dried Blast.

Water per cu. ft. of air $= \frac{1.75 \text{ grains}}{437.5}$	=	0.004	oz.
Water per cu. meter of air at — 4° C.	=	0.004	kg.
Water per cu. meter of air at 0° C	=	0 004	kg.
Oxygen in this moisture	=	0.0035	kg.
Oxygen in 1 cu. meter dry air at 0° C.	=	0.2984	kg.
Total oxygen per cu meter dry air at 0° C.	=	0.3019	kg
Volume of dry air used $= \frac{77.4}{0\ 3019}$	=	256.4	cu. meters.
Weight of oxygen present as air	=	76.5	kg.
Weight of nitrogen present $= 76.5 \times \frac{10}{3}$	=	255.0	kg.
Weight of moisture present $= 256.4 \times 0.004$	=	1 0	kg.

Composition of Slag: *Moist Blast.*

CaO, 45.5; MgO, 3.6; Al_2O_3, 10.9; SiO_2, 40.0 per cent.

Dried Blast.

CaO, 45 3; MgO, 3.8; Al_2O_3, 11.3; SiO_2, 39.6 per cent

Volume of Blast: *Moist Blast.*

Volume of air at 0° C. per 100 of pig-iron	=	322.8	cu. meters
Volume of moisture $= 4.52 \div 0\ 81$	=	5.6	cu. meters.
Volume of moist blast at 0° C.	=	328.4	cu. meters.
Volume of moist blast at 24° C. = 75° F	=	357.2	cu. meters.
Volume of moist blast per day	=	42,132,800	cu. ft.
Volume of moist blast per minute at 75° F.	=	29,260	cu. ft.

Dried Blast.

Volume of air at 0° C. per 100 of pig-iron	=	256.4	cu. meters.
Volume of moisture $= 1.00 \div 0.81$	=	1.2	cu. meters.
Volume of moist blast at 0° C.	=	257.6	cu. meters.
Volume of moist blast at — 4° C. = 25° F.	=	252.9	cu. meters.
Volume of moist blast per day	=	40,515,760	cu. ft.
Volume of moist blast per minute at 25° F.	=	28,136	cu. ft.

The volumes of air delivered compare very poorly with the stated piston-displacements, namely, 40,000 and 34,000 cu. ft. respectively. If the piston-displacements are reliable, the de-

livery efficiencies are 73 per cent. in pumping warm moist air, and 83 per cent. in pumping the cold, dried air. It appears to me more probable, that the delivery-efficiency is raised in the slower running, by the amount just indicated, than that the calculations of the volumes received by the furnace are grossly incorrect. The rather startling conclusion is thus reached, that the furnace received nearly as many cubic feet of dried air measured at 25° F., as it did of moist air measured at 75° F., although the engines were running 15.8 per cent. slower. The only explanation I have to offer for this is the increased delivery-efficiency; but possibly some other factor may partly account for it.

TABLE V.—*Heat Balance-Sheet* (*per* 100 *Kg. of Pig-Iron Produced*).

	Moist Blast	Dried Blast
DEVELOPED.		
Carbon to CO: 54 kg. × 2,430.	131,220	....
Carbon to CO: 38.25 kg. × 2,430.	....	92,950
Carbon to CO_2: 26.3 kg. × 8,100.	213,030	.....
Carbon to CO_2: 25.55 kg. × 8,100.	....	206,955
Heat in Blast: 103.1 × 382.	39,385	....
Heat in Blast: 81.4 × 465.	....	37,850
Total.	383,635	337,755
DISTRIBUTION.		
Reduction of Fe_2O_3:		
95 kg. Fe × 1,724	163,780	163,780
Reduction of SiO_2:		
1 kg. Si × 6,814	6,814	6,814
Expulsion of CO_2 from flux:		
19 kg. CO_2 × 950	18,050	18,050
Evaporation of moisture of charges:		
18.7 kg. × 606.5	11,342	11,342
Heat in the pig-iron:		
100 kg. × 250 (assumed)	25,000	25,000
Heat in slag:		
58 kg. × 400 (assumed)	23,200	....
56.8 kg. × 400 (assumed)	....	22,720
Decomposition of moisture of blast.		
4.5 kg. H_2O × 3,225	14,512	....
1.0 kg. H_2O × 3,225	....	3,225
Heat in escaping gases:		
156 calories × 281	43,836	....
124.6 calories × 191	....	23,799
Radiation, conduction, tuyere water and all other items (by difference)	77,101	63,025
Total	383,635	337,755

TABLE VI.—*Details of Heat Calculations for Table V.*

CARBON BURNT : *Moist Blast.*

CO in gases produced 448.5 × 0.223	=	100	cu. meters.
Carbon in this gas 100 × 0.54	=	54	kg.
Total carbon burnt	=	80.3	kg.
Carbon burnt to carbonic oxide (CO_2)	=	26.3	kg.

Dried Blast.

CO in gases produced 355.9 × 0.199	=	70.82	cu. meters.
Carbon in this gas 70.82 × 0.54	=	38 25	kg.
Total carbon burnt	=	63.8	kg.
Carbon burnt to carbonic oxide (CO_2)	=	25 55	kg.

HEAT IN BLAST. *Moist Blast.*

(Sm to 382°)

Heat-capacity of air = 322 8 cu. meters × 0 313	=	100 9	calories.
Heat-capacity of moisture = 5 6 cu. meters × 0.40	=	2.2	calories.
Heat-capacity of blast per degree Centigrade	=	103.1	calories.
Total heat in blast = 103.1 × 382	=	39,385	calories.

Dried Blast.

(Sm to 465°)

Heat-capacity of air = 256.4 cu. meters × 0.3155	=	80.9	calories.
Heat-capacity of moisture = 1.2 cu. meters × 0.40	=	0.5	calories.
Heat-capacity of blast per degree Centigrade	=	81.4	calories.
Total heat in blast = 81.4 × 465	=	37,850	calories.

HEAT IN WASTE-GASES : *Moist Blast*

(Sm to 281°)

Heat-capacity of N and CO = 400 cu. meters × 0.3106	=	121.2	calories.
Heat-capacity of CO_2 = 58.3 cu. meters × 0.446	=	26.0	calories.
Heat-capacity of H_2O (gas) = 23.1 cu. meters × 0.382	=	8.8	calories
Heat-capacity of gases per degree Centigrade	=	156.0	calories.
Total heat in gases = 156 × 281	=	43,836	calories.

Dried Blast.

(Sm to 191°)

Heat-capacity of N and CO = 299 cu. meters × 0.308	=	92.1	calories
Heat-capacity of CO_2 = 56.9 cu. meters × 0.421	=	24.0	calories.
Heat-capacity of H_2O (gas) = 23.1 cu. meters × 0.367	=	8.5	calories.
Heat-capacity of gases per degree Centigrade	=	124.6	calories.
Total heat in gases = 124.6 × 191	=	23,799	calories.

It is interesting to notice that while 77,101 calories were lost by radiation, etc. (per 100 kg. of pig-iron produced), when making 358 tons per day, that the mere increased rate of driving to 447 tons per day ought to lower this item to $77{,}101 \times \frac{356}{447} =$

61,830 calories, if the furnace were run no hotter. This calculated value is only 1,195 calories less than the amount shown to be lost by the balance-sheet, when using dry blast, thus giving a good check on the general accuracy of the latter.

Items of Saving by Dry Blast.

The total heat-requirement of the furnace, when running on moist blast (the total heat received by it and developed within it), is 383,635 calories, and when using dry blast, 337,755 calories, showing a net saving of 45,880 calories. This is accomplished in spite of the fact that 39,385 — 37,850 = 1,535 calories less is received from the blast, so that the real saving in the operation of the furnace itself may be called 45,880 + 1,535 = 47,415 calories. This would mean a saving of coke to the extent of 47,415 ÷ 383,635 = 12.4 per cent. even if the coke were not burned more economically in the furnace. But, from the ratio of CO to CO_2 in the gases, it can be shown that the coke is consumed with 9.65 per cent. greater economy when using dry blast, still further increasing the gain to more than 19 per cent.

Saving on Better Combustion of Carbon.

Using moist blast, 80.3 kg. of carbon consumed in the furnace furnished (see Table V.) 131,220 + 213,030 = 344,250 calories; using dry blast, 63.8 kg. furnished 92,950 + 206,955 = 299,905 calories. If the 63.8 kg. had been burnt no more efficiently than the 80.3, they would have furnished only $344{,}250 \times \frac{63.8}{80.3} = 273{,}510$ calories. It follows that, when using dry blast, 299,905 — 273,510 = 26,395 calories were saved by the more efficient combustion of carbon in the furnace.

This saving represents, in its turn, 6.9 per cent. of the primary heat-requirement of the furnace, making therefore a total economy of 12.4 + 6.9 = 19.3 per cent.

Table VII. gives the items of the economy in heat-requirement and therefore in fuel, as deduced from the foregoing discussion.

It is thus clear that of the total saving effected, less than 15 per cent. is directly attributable to the absence of moisture in the blast, the other 85 per cent. of the economy is due to indirect influences, viz.: (1) the heat in the waste-gases is less be-

TABLE VII.—*Economy in Heat-Requirements by Using Dry Blast.*

	Heat Saved.	Percentage of Requirements.
On decomposition of moisture of blast	11,287	2 95
On heat in waste-gases	20,037	5.25
On radiation, etc.	14,076	3 7
Better combustion of carbon	26,395	6.9
Smaller heat in slag	480	0.1
Less heat in blast	1,535	0.4
Total	83,819	19.3

cause the waste-gases are less in amount and therefore pass out cooled to a lower temperature; (2) the radiation loss is reduced because the furnace smelts faster, and these losses are in actual amount proportional to the time rather than to the amount of material smelted; and (3) the carbon is consumed better because there is much less carbon dioxide generated, and therefore there is less excess of carbonic oxide left unused in the waste-gases,—in other words, using moist blast, there is an excessive amount of carbon monoxide generated at the tuyeres in the effort to keep up the smelting-temperature with the moist blast, and only a certain limited amount of this can be oxidized to carbon dioxide by the oxygen supplied by the reduction of the solid charges,—while in using dry blast, the temperature of the smelting-zone is easily maintained, burning only 77 per cent. as much carbon at the tuyeres (58.05 kg. instead of 75.3 kg.) and the carbon monoxide formed, abstracts all the oxygen from the charges, and so is converted more largely into carbon dioxide than in the first case.

Smelting-Power at the Tuyeres.

The whole question of the economy obtained, therefore, converges towards the discussion of the generation of the heat necessary for smelting in the region of the tuyeres. To generate this amount of heat for the requisite temperature, with the production of no more carbon monoxide than is necessary to achieve reduction of the charges above, is the direction in which economy is to be obtained. The efficiency of hot blast is due to exactly this reason, that it increases the smelting-power of the tuyere-region without an increase in the carbon

monoxide formed, and with a higher temperature of the gases in the tuyere-region.

In another view of the matter, furnaces are limited by lack of smelting-power at the region of the tuyeres rather than of reducing-power in the upper part of the furnace, and any process which increases the former, without diminishing the latter below certain requisite limits, will strengthen the furnace at its weakest point, and result in corresponding economy. The hot blast accomplishes this by the positive addition of heat bodily; the dry blast improves matters by saving some heat otherwise lost in decomposing the moisture, thus also increasing the smelting-power. The drying of the blast is the exact equivalent of extra heating of the blast, both in its immediate and in its ultimate effects, but with the additional benefit of increasing the regularity of the temperature, smelting-power and general running of the furnace.

Only a small part of all the heat generated at the region of the tuyeres is represented by the heat in the melted pig-iron and slag. This is shown in Table VIII.

TABLE VIII.—*Comparison of Heat Generated at Tuyeres Using Moist Blast and Using Dry Blast.*

	Moist Blast	Dry Blast
	Calories	Calories
Heat in hot blast	39,385	37,850
Combustion of carbon to CO = 75.3 × 2430 =	182,979	....
Combustion of carbon to CO = 58 05 × 2430 =	....	141,062
Heat brought in and generated	222,364	178,912
Deduct heat to decompose moisture	14,512	3,225
Net smelting-down energy	207,852	175,687
Heat in melted pig-iron and slag	48,200	47,720
Percentage used for smelting down	(23.2 per cent.)	(28.0 per cent.)

The figures in Table VIII. show an apparent increase of only 4.8 per cent. in the efficiency of utilization of the heat generated at the tuyeres for smelting-purposes, but this is not the correct way to regard the matter. In the two cases quoted, there is an equal smelting done for the burning of 75.3 kg. of carbon at the tuyeres in the one case, and of 58.05 kg. in the other, a clear saving of 17.25 kg. of carbon burnt at the tuyeres per unit of pig-iron and slag melted, or 22.9 per cent. of the

carbon consumed at the tuyeres. This represents approximately, therefore, the total economy in fuel for the whole furnace. More important than that, however, it also represents increased speed of smelting, by the use of a constant blast. A constant blast burns a constant amount of carbon at the tuyeres in a given time, but if the furnace can be made to smelt a unit of pig-iron and slag with 22.9 per cent. less of carbon burned at the tuyeres, it should be expected, by using a constant blast, that the rate of smelting would be increased at least 22.9 per cent. by the new conditions, provided, of course, that the quantity of blast, measured at standard conditions, was kept constant.

A more logical way of viewing the matter of increased smelting-capacity is to consider the conditions with the use of moist blast as shown above, and then to consider what would happen if the moisture were suddenly to disappear from the blast, and the 14,512 calories absorbed in decomposing it to be suddenly restored to the furnace. The result would undoubtedly be a sudden increase in the heat available, and a rise in temperature of the melted iron and slag. Suppose this rise of temperature of the products were counteracted by increasing the burden of the furnace to such an extent as to bring back the temperature of pig-iron and slag to their primary state. When this condition of extra burdening had been reached, the temperature of the pig-iron and slag would be the same as before removing the moisture, and the 14,512 calories would have been all absorbed in doing an increased amount of smelting. In the actual case, the 14,512 calories were not all saved, but $14{,}512 - 3{,}225 = 11{,}287$ calories were, by removing 77.7 per cent. of the moisture; and the burden was correspondingly increased to keep the quality of pig-iron made the same as at first.

This saving was therefore applied exclusively to the increased smelting-capacity, because the increased burdening prevented or took up the increased available heat at the tuyere-region, and kept the temperature of the smelted products constant. The heat usefully applied for smelting was thus increased, for a given weight of carbon burned, from 48,200 calories to $48{,}200 + 11{,}287 = 59{,}487$ calories, equivalent to $11{,}287 \div 48{,}200 = 23.4$ per cent. Since the quantities of carbon burned at the tuyeres per day (the same as the relative quantities of

oxygen in the blast per day) were as 100 with moist blast to 96 with dry blast, the net increased smelting-capacity which should be expected from the increased quantity of heat available would be $23.4 \times 0.96 = 22.5$ per cent. The amount actually reached was 24.86 per cent.

The reason why a slightly greater smelting-capacity than that calculated was obtained is due to the fact that the products of combustion at the tuyeres (nitrogen, carbon monoxide and hydrogen) have a higher initial temperature when using dry blast, and are therefore capable of transmitting a given proportion of their heat-content more rapidly to the materials being smelted. This higher heat-potential can be calculated from the conditions existing before the tuyeres in the two cases, and its effect approximately allowed for. Its effect is to increase, somewhat, the rate at which the heat utilized for smelting is communicated to the materials to be smelted, but the main factor in the increased rate of smelting is rather the increased quantity of heat available.

The heat brought in and generated per kg. of carbon burnt before the tuyeres, using moist blast, is given in Table IX.

TABLE IX.—*Net Heat in the Gases Before the Tuyeres Using Moist Blast.*

	Calories.
By combustion to carbon monoxide,	2,430
By hot blast $= \frac{39,385}{75.3}$,	523
Total brought in and generated,	2,953
Absorbed in decomposing moisture $= \frac{14,572}{75.3}$,	193
Net heat available,	2,760

The heat in the white-hot carbon, however, which is burning, also goes into the products of combustion, and this carbon, just before it burns, is undoubtedly as near to the theoretical temperature of combustion as are the melted pig-iron and slag. If it be assumed that the carbon coming to be burnt is at the smelting-temperature of the pig-iron and slag, the required correction can be made with sufficient accuracy. It is assumed, for the purposes of this estimate, that the pig-iron and slag before the tuyeres are at a temperature of 1,700° C. This gives $1700 \times (0.5t - 120) = 730$ calories of heat brought to the

tuyere-region by the descending carbon ($0.5t - 120$ expresses the sensible heat in a kg. of carbon at temperatures above 1,000° C.). The total heat passing into the gaseous products of combustion at the tuyere-region is therefore $2,760 + 730 = 3,490$ calories.

This quantity of heat is generated, and exists immediately after the combustion has taken place, as sensible heat in the gaseous products of combustion. The latter are, per kg. of carbon burnt:

	Cu Meters.
$CO_2 = 22.22$ cu. meters — 12,	1.8519
$N_2 = (231\ 3$ kg. $\div$ 1.26) $\div$ 75.3,	3.3973
$H_2 = (0.5$ kg. $\div$ 0.09) $\div$ 75.3,	0.0598
Total,	5.3090

The theoretical temperature of the gaseous products of combustion before the tuyeres will be the total heat available, 3,490 calories, divided by the average heat-capacity of the above gaseous products from 0° to the temperature attained, to which latter is assigned t. Therefore $t = \dfrac{3,490}{5.3090\,(0.303 + 0.000027\,t)}$.

Whence $t = 1,861°$ C.

The heat brought in and generated per kg. of carbon burnt before the tuyeres, using dried blast, is given in Table X.

TABLE X.—*Net Heat in the Gases Before the Tuyeres Using Dry Blast.*

	Calories.
By combustion to carbon monoxide,	2,430
By hot blast $= \dfrac{37,850}{58.05}$,	652
Total brought in and generated,	3,082
Absorbed in decomposing moisture $\dfrac{3,225}{58.05}$,	56
Net heat available,	3,026
Heat furnished by descending carbon,	730
Total heat in gaseous products of combustion,	3,756

The products are, per kg. of carbon burnt:

	Cu Meters.
$CO = 22.22$ cu. meters $\div$ 12,	1.8519
$N_2 = (225\ 0$ kg. — 1.26) — 58 05,	3.4949
$H_2 = (0.1$ kg. — 0.09) $\div$ 58.05,	0.0213
Total,	5.3681

$$\text{Whence } t = \frac{3{,}756}{5.3681\ (0.303 + 0.000027\ t)} \text{ and } t = 1{,}965°\ C.$$

The temperatures just calculated are those which would be measured by a pyrometer placed in the hottest point at the tuyere-zone. They show a temperature 104° C. = 187° F. higher when working with dry blast than when using moist blast. This is not the temperature of the smelted-pig-iron and slag, but that of the gases before imparting or losing any of their heat for that purpose. If it be assumed that the rapidity with which they impart their heat is proportionate to the two temperatures, the hotter gases should melt the stock down 5.6 per cent. faster than if at the lower temperature.

To state the case succinctly, the gaseous products of combustion using dry blast have 23.4 per cent. more of their heat utilizable per unit of time for smelting-purposes, and have an additional relative heat-potential of 5.6 per cent. to assist in imparting this heat more quickly, making a total relative smelting-capacity of 123.4 × 1.056 = 130.3 to 100, or 30.3 per cent. increase if the quantity of oxygen blown in per unit of time were constant. But, since the quantity of oxygen actually blown in per day in Mr. Gayley's experiment was as 100 for moist blast to 96.3 for dry blast, the rapidity of smelting should have been as 100 to 130.3 × 96.3 = 100 to 125.5 or a daily increase of 25.5 per cent.

I conclude, that since Mr. Gayley obtained an increase of 24.86 per cent., the views here advanced give a satisfactory explanation of the increased smelting-power of the furnace, that the heat saved by absence of moisture is directly utilized for increased smelting-capacity, aided furthermore by a higher heat-potential which of itself alone would increase the smelting-rate about 5 per cent., the two factors working simultaneously and necessarily interdependently towards the total effect.

In conclusion it may be said that the increased efficiency obtained by Mr. Gayley could theoretically have been obtained by an increased temperature of blast alone, viz., by using the moist blast at 597° C. (1,107° F.), instead of at 382° C. (720° F.). Such increase would produce the effects of quicker running and economizing coke to the quantity noted with dry blast, but would still leave the furnace subject to the irregularities insep-

arable from using ordinary air with its varying temperature and content of moisture. The increased regularity of running of the furnace and quality of product, due to uniform temperature of air supplied to the blowing-engine and uniform temperature before the tuyeres, is the fundamental economic justification for Mr. Gayley's innovation: the increased rate of driving and economy of fuel alone could be obtained more cheaply by increasing the capacity of the stoves.

T. W. Robinson, Chicago, Ill. (communication to the Secretary*):—The international discussion that has been evoked by Mr. Gayley's latest contribution to the annals of iron and steel is a striking testimonial to the value of his paper. If the figures given can be considered typical of what may be reasonably expected from the use of the dry blast, its innovation is bound to prove of the greatest importance. That the problems of cause and effect are intensely interesting, both from their commercial and scientific aspect, is reflected in the wide-spread interest that has been evinced. Those questioning the sincerity of the Isabella test, or the accuracies of recording the results, will not be considered by those acquainted with Mr. Gayley or his past work. As to the causes for results so at variance with accepted ideas, the discussion has brought out little that is convincing. It is strange that greater stress has not been placed on what Mr. Gayley, himself, has had to offer in way of explanation. Stated briefly, his reasons for the higher efficiency obtained, are, greater uniformity of practice and ability to reduce the heat reserve. The essence, of course, of the Isabella demonstration is that the furnace, working under as strictly comparative conditions as could be devised, showed a saving of approximately 400 lb. of coke per ton of iron through the substitution of dry blast for ordinary blast. The natural inference was that this result must be directly due to the saving of the heat ordinarily dissipated by the usual introduction of the moisture. Calculation, however, shows that the heat units involved in the evaporation and disassociation of the moisture removed by refrigeration represent less than one-fourth of the amount of the fuel actually saved. How can such an anomaly be explained?

* Received April 29, 1905.

In studying this question one naturally looks, first, to the conditions under which the test was made. We have Mr. Gayley's assurance that every care was exercised to make the conditions under which the furnace was operated strictly comparable. The records at Isabella, which were thrown open to inspection, verified this fact. Raw material, equipment and general practice were shown to be practically constant during the test. The only appreciable variable was the character of the blast. Mr. Gayley's paper covered an operation of one furnace for only about six weeks, during which the fuel was reduced approximately 400 lb. It has been questioned whether so short a test might not easily lead to erroneous conclusions. Fortunately for the advocates of the dry-blast process, further experiments at Isabella have corroborated the initial returns. Since the paper was presented, the writer has examined the records of four consecutive months on dry blast at the two adjacent Isabella stacks. During this period, both were operated under practically identical conditions save that one was run with dry blast and the other with ordinary blast. The dry blast-furnace showed an average coke-consumption of 437 lb. per ton of iron less than the other. To make the experiment more conclusive the blast on the two stacks was interchanged, the one formerly on dry air being put on ordinary air and vice versa, the practice otherwise remaining the same. In less than a week the furnaces had exchanged places in production and fuel-consumption. This further demonstrated that any differences that might have existed in plant and practice were not of much consequence. The logical conclusion is that the refrigeration of the blast must, in some manner, be accountable for the surprising results obtained.

The problem, accordingly, resolves itself—(1) into a study of the effect of the refrigerating-process on the character of the blast itself and (2) of the influence of the dry blast on the furnace reaction.

Refrigeration, as carried out at Isabella, eliminated about three-quarters of the normal moisture and materially increased the density of the blast at the blowing tubs. The fuel directly saved by the elimination of the moisture, as based upon Mr. Gayley's figures of 69 lb. of water removed per ton of iron, is equivalent to less than 80 lb. of coke. If we add to this the

saving, incident to the increased temperature of the blast, there is still a large part of the total saving unexplained.

But what effect has the increased density? The records show, that, where formerly the engines were making 114 revolutions, the refrigerating of the blast necessitated a reduction to 96 revolutions. If, to be conservative, we assume the ordinary temperature of the air to be 75° F. and that of the refrigerated blast, as it enters the blowing-tubs, to be 22° F., and allow the refrigerated blast to have an increased pressure of 0.3 oz., due to the use of the auxiliary fan, we find that the actual weight of the air used per unit of time is in the ratio of 100 to 93.6. In other words: by slowing down the engines from 114 revolutions to 96 revolutions, there was a reduction of a little over 6 per cent. in actual weight of air blown. In volume the reduction at the blowing-tubs amounted to 15.8 per cent. This, however, under equal furnace-pressure, would have been reduced to a difference in volume of 6 per cent. at the tuyeres, had the stoves heated the air, in each case, to a like temperature. While weight and volume did not correspond at the engines they would have done so at the furnace had the stove-capacity been sufficient. That the stoves did not, in each instance, heat the blast to the same temperature is merely incidental and not essential to the case in point.

Accordingly, as increasing the density at the blowing-tubs does not change the volume of air, or the weight of air, or the weight of oxygen that enters the furnace, if compensated for by lower engine-speed, its only appreciable effect is to increase the engine-efficiency. The more dense the air, the greater the weight that can be blown per revolution, that is all. Hence it is clear that the increased density of blast, due to refrigeration, cannot rationally be offered as a cause for the decreased coke-consumption. Further, the only practical result in decreasing the revolutions from 114 to 96 was to reduce the blast from 40,000 cu. ft. per minute to about 37,400 cu. ft. per minute. This is a comparatively small reduction and one, of course, capable of attainment without the intervention of refrigerating-machinery.

Mr. Gayley says, that, by reducing the revolutions from 114 to 96, the volume of blast was reduced 6,000 cu. ft. per minute. He cites this fact in calling attention to the influence that the

increased density of the air had upon the steam-economy. His statement is correct, but liable to misconstruction unless the material difference in the relation of weight and volume in ordinary and refrigerated temperatures is appreciated. They are, of course, not comparable.

As usually calculated by piston displacement, the difference in the dry and the ordinary blast that entered the furnace was 2,600 cu. ft., not 6,000 cu. ft. Apparently, then, neither increased density nor reduction of blast could explain the balance of the fuel still unaccounted for.

Turning now to the effect of the dry blast on the furnace, we know that its introduction was quickly followed by increased production and decreased fuel-consumption. Analyzing the details it is perceived that the furnace on dry blast ran with lower top-temperature, with an increased per cent. of carbonic acid in the waste gases, with a less amount of air per unit of coke and with lower pressure of blast. The differences are indicative of lower fuel, and are the results of less coke-consumption, not causes for it. We note that the iron produced is more uniform in analysis; that there is less slipping of the furnace; that the flue-dust has been reduced from 5 per cent. to 1 per cent. and that, generally, the dry-blast furnace is more regular in its operation than the other. In studying the possible causes for fuel saving, it has been shown that the difference existing in plant and raw material had no appreciable effect. The influence of increased density and decreased revolutions of engines was practically negative. Allowance for the heat-equivalent of the eliminated moisture and for the increased temperature of blast does not explain the results that were obtained. One point, however, that has not yet been discussed, is the greater regularity of the dry-blast furnace. That greater regularity ought to follow refrigeration will be apparent, if the large amount of moisture usually introduced is appreciated and the extent of its hourly and daily variations fully realized. If anyone questions this, let him consider what the effect would be of injecting at the tuyeres under a 40-ft. head a stream of water that varies from 0.75 to 1.5 in. in diameter. This is practically what a humidity varying from 2 to 6 grains per cu. ft. means, when 40,000 cu. ft. of air is used per minute, even though introduced as super-heated steam.

By reducing the moisture two-thirds or more, and by causing the residue to become nearly constant, the refrigerative process cannot help but have an important effect upon regular work.

Now it may be considered axiomatic, that, under any given condition of raw material and equipment, minimum fuel will accompany maximum regularity. It is no uncommon occurrence to see a difference of 400 lb. of coke per ton of iron follow the swinging of a furnace from uniform to irregular work. Ordinarily, irregular work is a direct sequence to scaffolding, even though it be embryonic. As to the cause of scaffolding—its name is legion. Lack of uniformity in any of the elements of blast-furnace practice is conducive to a changeable zone of fusion and to accretion. A change of 50° F. in stove-temperature will often raise the pressure and sometimes cause more serious trouble. Largely, to the extreme variation of moisture in the outer air and in the engine-room is, undoubtedly, attributable the fact that there is not a greater difference in fuel between summer and winter. A compilation of the average monthly results for ten years, of eight furnaces at South Chicago, shows that for June, July and August there was an increased fuel-consumption of but 21 lb. of coke per ton of iron over the winter months. As these furnaces were working, during this long period, under conditions that were practically comparative, the result is of more than ordinary interest on account of so many variables being minimized. The possibility of maintaining more uniform conditions through protecting the in-coming blast from steam-contamination, appears worthy of more careful consideration than is ordinarily given.

The blast-furnace is an exceedingly rough piece of mechanism, but, withal, a most delicately poised apparatus, when working under greatest efficiency. When normal, its chemical and physical laws are subject to reasonably accurate deductions; but, unfortunately, its regular condition is one of irregularity. This is paradoxical, but just here lies the main reason why Mr. Gayley is obtaining something in practice that theory does not fully explain. From a laboratory standpoint, the reactions involved in iron-smelting are simple and well understood. As actually encountered in the furnace they are exceedingly complex and difficult to measure—especially so when there is irregularity.

The question of removing the moisture from the blast is, of course, an old story. Many have considered the subject and discarded it as an unfeasible proposition, not only for want of a proper method, but from failing to recognize its latent possibilities upon more uniform practice. Twenty years ago the writer was cognizant of comparative tests simultaneously made by Messrs. James Gayley, E. C. Potter and F. A. Emmerton, at Pittsburg, Chicago and Joliet, upon the humidity of the air and its effect upon the furnace. That, after so long a study, Mr. Gayley has been able to make the Isabella demonstration, despite practical and scientific discouragement, is a fitting climax to his persistency and ingenuity. Theoretically, the end did not warrant the means. But, in iron-smelting, theory has had to be remodeled many times to square with actual results. Numerous reasons and hypotheses have been advanced in the past to prove why it would be impossible to obtain certain ultimates in coke and product, which were later achieved and surpassed; and history repeats itself. The essential reason for the more effective work that followed the replacing of old-time methods by scientific management was the ability to command more uniform conditions. In later years the evolution of furnace-practice has proceeded along divergent lines. On the one hand, more perfect mechanical appliances and a better understanding of the principles involved have tended to greater uniformity and lower fuel. On the other, much larger units, heavier blowing and, in this country, the advent of the finer ores from the Mesabi Range, have promoted irregularity and higher fuel.

Because the Isabella furnace was consuming 2,147 lb. of coke before the dry blast was applied, the question has been raised whether the subsequent saving of 421 lb. is not misleading, on account of being based on poor practice. Those, who know the facts, are aware that 2,150 lb. of coke per ton of iron more nearly represent the average practice to-day in the United States, than 1,900 lb. or any less. It is self-evident that a furnace consuming 1,900 lb. would not present the same opportunities for reduction as would one using 2,147 pounds. But the opinion that the Isabella practice was poor is neither warranted by the conditions that existed nor by the results that are gener ally being obtained in this country. Whether the Isabella re

sults can be considered a fair index of what the dry blast would accomplish elsewhere, will depend upon individual conditions. It is certain, however, that the refrigeration process will ordinarily pay a handsome return on the investment, and indications now point to its being widely introduced.

As to the influence of heat reserve, to which Mr. Gayley calls attention, every practical furnace-man knows how exceedingly difficult it is to measure correctly the actual reserve that is being carried at any given time. In the Isabella case, an examination of the records shows that, during the four or five months of cold-blast practice, whatever reserve was carried lay rather in the burden than in the stoves. As the amount of reserve heat is best measured by the analysis of the iron that is being produced, it is significant that, during the period mentioned, the iron from the furnace with ordinary blast was no hotter than that from the furnace with dry blast. There was more variation in the percentage of silicon, but the average indicated that the maximum possible burden was being maintained on one as on the other. Accordingly, while the question of heat reserve might be an important one, the evidence fails to show that it was much of a factor in the Isabella test.

From what has gone before, the logical conclusion is, that greater regularity superinduced by refrigeration is largely the cause of the extraordinary results at Isabella. This may not be capable of scientific demonstration, but, until the usual reactions of the blast-furnace can be more accurately measured, I am content to rest rather upon actual results and rational conclusions than upon scientific deductions that are antagonistic to facts.

Edward de Mille Campbell, Ann Arbor, Mich. (communication to the Secretary*): In the discussion of Mr. Gayley's paper on The Application of Dry-Air Blast to Manufacture of Iron, most of the authors have attempted to explain the remarkable results solely on theoretical grounds.

As Mr. E. Windsor Richards has explained,[1] Mr. Dawson showed, more than one hundred years ago, that blast-furnaces are influenced by variation in the amount of moisture in the

* Received August 11, 1905.

[1] *Trans*, xxxv., 1022.

air, more fuel, as a rule, being required in summer than in winter. This fact has been a matter of general knowledge to blast-furnace men since Dawson's time, but they did not seem to have appreciated the extreme sensitiveness of a blast-furnace to variations in atmospheric moisture, until Mr. Gayley demonstrated the remarkable improvement which can be brought about by reducing to a small and practically constant amount the amount of water carried in by the blast.

Dr. Raymond seems to be the only one of those who have contributed to the discussion of Mr. Gayley's paper who appreciates the underlying cause of the great value of Mr. Gayley's invention. The great economy in operation is not due to the saving of energy required for dissociation of water in the blast, which it has been shown by others does not exceed 3 or 4 per cent. of the total energy evolved by the fuel, but is due to uniformity of conditions in the hearth, which permits a uniform temperature to be maintained in that part of the furnace. That the great value of dry air is principally due to the elimination of the daily hygrometric variations may be clearly seen from a study of the observations made by me 16 or 17 years ago, while I was chemist for the Dayton Coal & Iron Co., of Dayton, Tenn.

Before going south, I had held a similar position with the Sharon Iron Co. at Sharon, Pa. One of the first things I noticed on going to the Dayton furnace, which was so much further south than the one at Sharon, was that the southern furnaces at that time apparently had much more difficulty in running uniformly, especially in the winter months, than did the furnaces which were located further north. After watching the furnaces carefully for some time, I noticed that the furnaces usually took more charges during the night-shift than during the day. I also noticed that on several occasions, when there was a marked change in the weather, the furnace seemed to be influenced by the change. The only cause I could see for the furnace driving faster at night than during the day-time was that at night there was apt to be a heavy precipitation of dew with consequent diminution in the amount of moisture blown into the furnace. The effect of this was usually manifest about 9 or 10 p.m., when there was a marked increase in the rate of driving, which was normally maintained until about the same hour in the morning; that is, the furnace ordinarily responded

to the change in the amount of moisture within about 4 or 5 hr. after the change had taken place. After observing the furnace for some months, I became so impressed with the sensitiveness of the blast-furnace to atmospheric changes, that I decided to make a systematic set of observations to determine to what extent these changes affected the operation of the furnace.

To this end an ordinary hygrometer, consisting of a dry-bulb thermometer and a second thermometer, the bulb of which was wrapped in lamp-wicking dipping in water, was constructed. This hygrometer was placed in the stock-house, where there was a free circulation of air, but protected from direct drafts, which would cause excessive evaporation from the wet bulb. From the difference in the reading of the dry-bulb and wet-bulb thermometers, the dew-point (the temperature at which the air would be saturated with moisture) was determined. The dew-point having been determined, the amount of moisture per cubic foot of air was found from physical tables, and the figures so found were used as a basis for calculating the amount of coke required to dissociate the water carried in by the blast. Four readings per day were made, at 5 a.m., 12 m., 5 p.m. and midnight. At the time the readings were taken to determine the dew-point, the number of revolutions of the blowing-engines was also recorded.

From the furnace-books, the number of tons of each grade of iron produced daily was taken, as well as the number of pounds of ore charged into the furnace for each unit-weight of fuel.

In order to determine the amount of coke required per day, for the decomposition of the moisture introduced by the blast, the following assumptions were made: (1) that the blast was on actually 23 out of 24 hr., a loss of 1 hr. being allowed for the time during which the blast was off while flushing the cinder or casting the iron; (2) that on account of the inefficiency of the blowing-engines, and leaks in the hot-blast stoves, mains, etc., 60 per cent. only of the piston-displacement actually entered the furnace; (3) that $\frac{9}{10}$ of the carbon of the coke reached the neighborhood of the tuyeres, where the heat developed by its combustion to carbon monoxide was available for dissociating the water vapor.

The coke we were required to use contained an average of 21 per cent. of ash and about 75 per cent. of carbon. I selected the figures, 23 hr.—60-per cent. piston-displacement, and 90 per cent. of the carbon of the coke reaching the tuyeres—as conservative figures. If the blast were on more than 23 hr.; or more than 60 per cent. of the piston-displacement entered the furnace; or less than 90 per cent. of the carbon of the coke reached the tuyeres, the figure showing the amount of coke required for the decomposition of the moisture would be correspondingly increased.

The term "grade-heat" was one invented in order to enable the temperature of the furnace, so far as it was indicated by the kind of iron being made, to be expressed in figures, and recorded graphically. At the time these notes were made we had no reliable figures showing the temperature existing in the lower part of the blast-furnace. Also, at this same time, the iron was graded by fracture, the grades being arranged according to the temperature of the furnace at the time the iron was produced as follows:—white, mottled, gray forge, No. 3 foundry, No. 2 foundry, No. 1 foundry, No. 1 soft, No. 2 soft, and silver gray or glazed iron. Since the furnace was usually worked on foundry iron, a grade-heat of 1.00 was empirically adopted as representing the temperature existing in the furnace at the time No. 1 foundry iron was being produced. If the furnace cooled off sufficiently to produce No. 2 foundry iron, the grade-heat, 0.98, was adopted; similarly, 0.96 represented No. 3 foundry iron, 0.93 gray forge, 0.90 mottled and 0.88 was the grade-heat employed when the furnace was cold enough to produce white iron. On the other hand, when the furnace was hotter than was necessary to produce No. 1 foundry iron, a grade-heat of 1.02 was employed to indicate No. 1 soft iron, and 1.03 to indicate No. 2 soft; and if the furnace became hot enough to produce silver gray or glazed iron, this was indicated by a grade-heat of 1.05. While these grade-heats probably do not express the exact ratios of the temperature existing in a blast-furnace at the time the different grades of iron are being produced, they do represent the relative temperature, and afford a means of expressing, in figures, the conditions of a blast-furnace. In order to determine the grade-heat for the blast-furnace for any given day, resort was had to the daily report of

the iron grades. From this report the number of tons of each grade of iron was obtained; and these amounts were each multiplied by the proper grade-heat, and the sum of these products was divided by the total number of tons produced. For example, if the furnace made 105 tons in a day, consisting of 40 tons of No. 2 foundry, 30 tons of No. 3 foundry, and 35 tons of gray forge, the mean grade-heat would be found as follows:

40 x 0.98, ...	39.2
30 x 0.96, ...	28.8
35 x 0.93, ...	32.55
	100.55

100.55 – 105 = 0.957, the mean grade-heat of the day.

Daily observations were made on the two blast-furnaces of the company from July, 1888, to August, 1890, inclusive, at which latter time I resigned my position to accept the chair of Metallurgy and Analytical Chemisty at the University of Michigan. The results of all these observations were plotted in curves which showed the dew-point, yield of iron per day, the grade-heat and the weight of the ore charged per buggy.

From the original curves, representing a period of 26 months, which have been kindly lent to me by Mr. W. J. Isaacson (Managing Director of the Dayton Coal & Iron Co.), I have selected 16 typical instances showing the influence of variations in the dew-point on the working of the furnace. The results of these variations are given in Table I., and the data of all the Sections of this table are shown graphically in Figs. 1 to 16.

A study of these curves revealed some exceedingly interesting relations,—especially the sensitiveness of a well-burdened furnace to atmospheric changes. In studying these curves, it must be borne in mind that the variations in atmospheric moisture are not the only irregularities in the material entering the furnace, because the solid material—coke, iron-ore and limestone—are liable to vary from day to day. The company operated furnaces No. 1 and No. 2, which were apparently alike in size (75 ft. high, 18 ft. bosh, 9 ft. hearth), each having eight 6-in. tuyeres. No. 1 furnace was considerably further from the engine-house than was No. 2, which seemed to be about the only difference in the furnaces, yet No. 1 would never average as large a yield of iron, nor would it carry as heavy an ore-

burden, as would No. 2. A study of the curves shows that while No. 1 furnace was, in general, affected by atmospheric changes, like No. 2, the extent of the changes was not usually as strongly marked as in the latter furnace. If a furnace is carrying a full burden of ore, the heat being well concentrated in the hearth, with a cool top; and the dew-point rises—that is, the amount of moisture introduced at the tuyeres is increased—the effect of this begins to show within 5 or 6 hr., either through a falling-off in the grade-heat alone, or in a cooling-off of the furnace accompanied by slower driving. On the other hand, if a furnace is running normally, with the heat well down in the hearth, with the top cool, and there is a fall in the dew-point, the effect is first shown by a rise in the grade-heat and an increase in the rate of driving,—that is, an increase in the output of iron. If the dew-point remains persistently low, and the ore-burden is not increased, the effect is frequently to raise the height of the fusion-zone, after two, three or sometimes four days, the grade-heat often falling-off somewhat as the height of the fusion-zone is increased. If, after several days running with an abnormally high fusion-zone, the dew-point again rises, the effect is frequently to lower the fusion-zone suddenly, coincident with the falling-off of the grade-heat. This sudden lowering of the fusion-zone causes the stock to come in contact with those portions of the bosh-walls which were superheated during the period of low dew-point, tending to stick and form scaffolds. These incipient scaffolds afterward give way under the weight of the stock, causing slips and slides, with accompanying troubles.

If a furnace is normally "underburdened," if such an expression may be used, a change in atmospheric moisture does not usually produce as marked an effect on the furnace, since the total heat-energy developed in the furnace is greater than should be required; and the effect of an absorption of heat by increased amount of moisture in the blast would not be as noticeable as if the furnace was carrying a full burden. On the other hand, No. 1 furnace, which was usually underburdened, had a greater tendency to form incipient scaffolds than did No. 2, which usually carried a full burden.

Up to the time these systematic observations were made, much trouble has always been experienced from scaffolds, especially during the months of January and February. During

these months the fluctuations of the moisture in the south is apt to be very great, and, consequently, the conditions conducive to the formation of scaffolds occur most frequently. Moreover, the dew-point is apt to be low for several days,—thus tending to increase the height of the fusion-zone,—and then rise quite rapidly, causing a sudden contraction in the fusion-zone, with a tendency toward the formation of scaffolds. When the most frequent cause of these irregularities was appreciated, proper steps were taken whenever a marked change in the dew-point indicated the necessity. By a careful control of the burden, etc., according to the indications, as shown by the hygrometer, many of these irregularities, which had previously been such a serious cause of trouble, could be overcome. Thus, in many instances, when the furnace-man perceived that the dew-point was rapidly rising, he would put in an extra charge of fuel without any ore. This extra fuel would prevent the grade-heat from falling, but, as it was not registered in the furnace-book, it is not shown in the curves.

In the summer months, although the dew-point was very high, the fluctuations were usually confined to rather narrow limits, so that the furnace would not carry as heavy an ore-burden as during the colder months; but the work of the furnace was apt to be more regular than during the winter months.

While it is extremely difficult to express in numbers the exact saving that would be effected in blast-furnace practice by removal of the moisture from the air, my two years of close observation of the influence of atmospheric changes on the furnace-operation convinced me that at least two-thirds if not three-fourths of the irregularities in blast-furnace running were directly attributable to the varying amounts of moisture entering the furnace. The lack of uniformity in the grade of the iron, and the irregularity in the running of the furnace, are due not so much to the amount of moisture entering into the furnace at a given time, as the fluctuations in the amount of moisture on different days.

I cannot but feel that, if Mr. Gayley has succeeded, as he apparently has, in reducing the amount of moisture to a small and constant amount, his invention will eventually prove to be the most important advance in the metallurgy of pig-iron since the introduction of the hot blast by Neilson, more than 75 years ago.

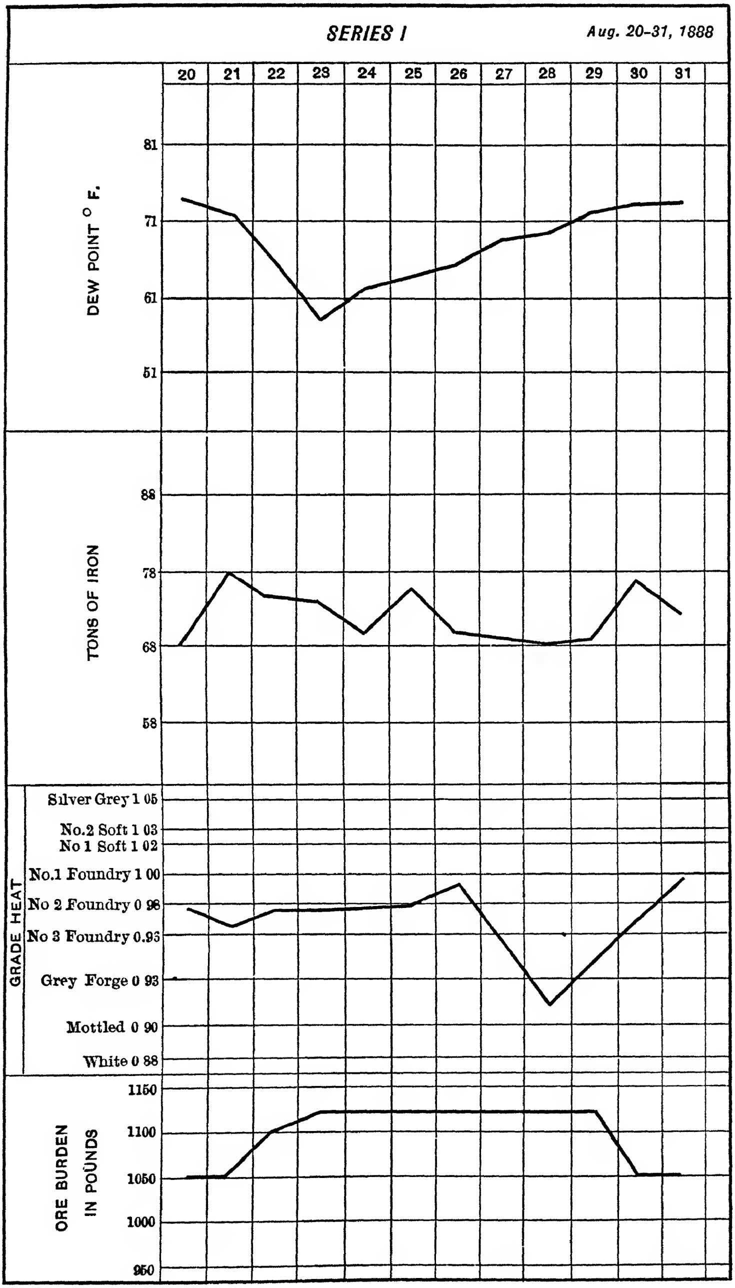
TABLE I.—*Data of Blast-Furnace Operations at Dayton, Tenn.*

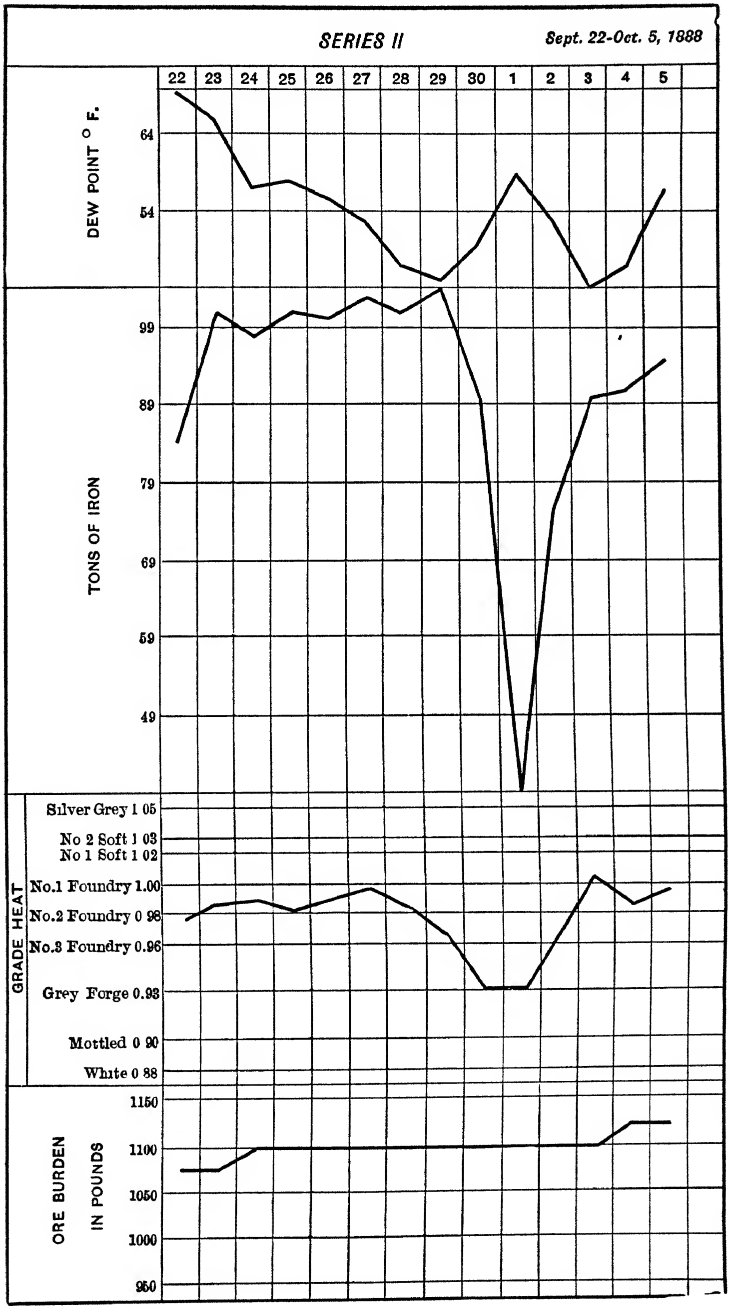
Series.	Date.	Dew-Point.	Coke for Decomposition of Moisture.	Daily Output of Iron	Grade-Heat.	Ore-Burden.
	1888.	°F.	Pounds.	Tons.		Pounds
I.	Aug. 20.	74	32.48	68	0.977	1,050
	Aug. 21.	72	29.72	78	0.969	1,050
	Aug. 22.	66	24.92	75	0.975	1,100
	Aug. 23.	58	18.11	74	0.975	1,125
	Aug. 24.	62	22.03	70	0.979	1.125
	Aug. 25.	65	24.92	76	0.980	1,125
	Aug. 26.	66	24.50	70	0.993	1,125
	Aug. 27.	69	26.07	69	0.957	1,125
	Aug. 28.	70	23.44	68	0.915	1,125
	Aug. 29.	72	27.67	69	0.945	1,125
	Aug. 30.	73	30.69	77	0.973	1,050
	Aug. 31.	73	30.69	71	0.997	1,050
II.	Sept. 22.	70	26.91	84	0.976	1,075
	Sept. 23.	66	24.50	101	0.985	1,075
	Sept. 24.	57	18.13	98	0.988	1,100
	Sept. 25.	58	18 44	101	0 983	1,100
	Sept. 26.	56	17.54	100	0.989	1,100
	Sept. 27.	53	15 83	103	0.997	1,100
	Sept. 28.	47	13.28	101	0.985	1,100
	Sept. 29.	45	12.79	104	0.968	1,100
	Sept. 30.	50	14.27	90	0.930	1,100
	Oct. 1.	59	17.58	39	0.930	1,100
	Oct. 2.	53	14.87	76	0.964	1,100
	Oct. 3.	44	11.16	90	1.003	1,100
	Oct. 4.	47	12.51	91	0.989	1,125
	Oct. 5.	57	18.60	95	0.996	1,125
III.	Oct. 27.	60	19.56	92	0.970	1,175
	Oct. 28.	48	12.49	103	0.918	1,175
	Oct. 29.	43	10.66	104	1.000	1,175
	Oct. 30.	47	12.62	90	1.005	1,175
	Oct. 31.	51	13.99	99	0.975	1,175
	Nov. 1.	53	14.74	101	0.953	1,225
	Nov. 2.	62	19 99	101	0 930	1,225
	Nov. 3.	58	17.14	90	0.958	1,225
	Nov. 4.	53	15.29	95	1.020	1,225
	Nov. 5.	59	19.41	104	0.997	1,225
	Nov. 6.	63	21.25	93	0.962	1,225
IV.	Dec. 16.	52	14.62	101	0.991	1,200
	Dec. 17.	45	11 04	91	0.945	1,200
	Dec. 18.	33	7.09	101	0.984	1,200
	Dec. 19.	25	5.65	90	1.026	1,200
	Dec. 20.	27	6.56	98	1.029	1,250
	Dec. 21.	28	6.15	105	1.020	1,250
	Dec. 22.	26	5.70	101	0 986	1,250
	Dec. 23.	21	4.38	89	0.984	1,250
	Dec. 24.	40	10.21	93	1.018	1,200
	Dec. 25.	43	11.33	93	1.008	1,200
	Dec. 26.	44	11.06	79	1 008	1,200
	Dec. 27.	37	8.40	69	0.945	1,200
	1889.					
V.	Feb 12.	26	6.00	78	1.012	1,050
	Feb. 13.	33	7.96	89	1 082	1,050
	Feb. 14.	44	11.75	89	0.917	1,050
	Feb. 15.	51	14.50	80	0.900	1,050
	Feb. 16.	57	16.88	80	0.904	1,050
	Feb. 17.	58	18.11	80	0.930	1,075

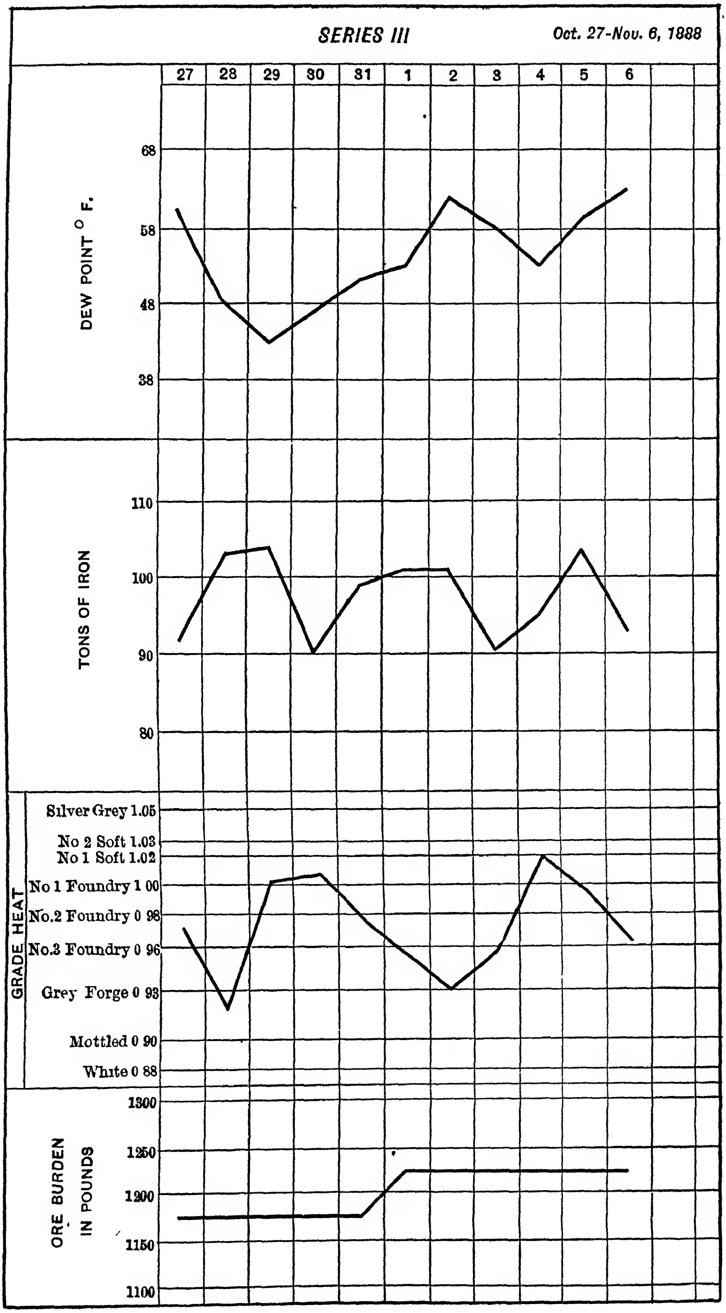
	Feb. 18.	33	7.62	88	0.962	1,125
	Feb. 19.	24	5.49	95	0.994	1,150
	Feb. 20.	29	6.73	96	0.993	1,150
	Feb. 21.	29	6.61	86	0.940	1,150
	Feb. 22.	32	7.41	87	0.986	1,150
	Feb. 23..	25	5 60	74	1.013	1,150
VI.	Apr. 1.	52	14.22	84	0.936	1,150
	Apr. 2.	48	12.61	98	0.985	1,150
	Apr. 3.	46	11.85	100	1.041	1,150
	Apr. 4.	38	8.94	102	1.001	1,150
	Apr. 5.	41	10.16	91	1.010	1,150
	Apr. 6.	28	6.48	101	1.007	1,150
	Apr. 7.	39	8 97	105	0.992	1,150
	Apr 8.	41	9.98	102	0.942	1,150
VII.	Sept. 16.	70	27.39	95 5	0 964	1,060
	Sept. 17.	63	21.82	94.5	0 970	1,060
	Sept. 18.	48	13.64	101	1.020	1,060
	Sept. 19.	47	12.40	102	0.992	1,080
	Sept 20.	52	15.42	103	1.005	1,100
	Sept. 21.	53	15.70	102	0.978	1,060
	Sept. 22.	53	15.01	101	0 932	1,060
	Sept. 23.	59	19.42	101	0.951	1,060
	Sept. 24.	64	23.53	98	0 999	1,060
	Sept 25.	61	20.42	101	0.967	1,060
VIII.	Oct. 8.	37	8.64	102	0.960	1,100
	Oct. 9.	44	11.16	102	0 937	1,100
	Oct. 10.	51	14.25	102	0.945	1,060
	Oct. 11.	53	14.74	102	0.920	1,060
	Oct. 12.	59	20.42	102	0 998	1,060
	Oct. 13.	59	20.75	97	0.968	1,060
	Oct. 14.	39	Cleaning flues.			
	Oct. 15.	41	10.07	85	0 972	1,060
	Oct. 16.	41	10.42	92	0.933	1,060
	Oct. 17.	50	14.27	102	0 974	1,060
	Oct. 18.	46	11.96	92	0.960	1,060
	Oct 19.	51	13 74	96	0 955	1,060
IX.	Nov. 26.	52	15 41	94	0.995	1,060
	Nov 27.	45	11.55	94	0.996	1,040
	Nov 28	31	7.26	96	1 007	1,040
	Nov. 29.	25	5.51	94	0 968	1,040
	Nov. 30.	28	6.37	98	0 968	1,040
	Dec. 1.	34	7.73	96	0.939	1,040
	Dec. 2.	28	6.37	98	0 957	1,040
	Dec. 3.	40	9.61	96	0.946	1,040
	Dec. 4.	42	10.16	96	0 978	1,040
	Dec. 5.	48	12.61	95	0.942	1,040
	Dec. 6.	50	14.51	95	0.975	1,040
	Dec. 7.	57	17.19	94	0.976	1,040
	Dec. 8.	57	17.04	96	0 957	1,040
	Dec 9.	61	19.70	94	0 956	1,020
	Dec. 10.	60	19.56	96	0 971	1,020
X.	Dec 15.	46	12.18	95	1.000	1,060
	Dec. 16.	47	12.84	96	0 994	1,060
	Dec. 17.	56	17.54	97	0.996	1,060
	Dec. 18.	57	18.13	95	1.020	1,060
	Dec. 19.	57	18.13	93	0.979	1,060
	Dec. 20.	59	17.74	64	1.020	1,060
	Dec. 21.	60	19.91	94	0.987	1,060
	Dec. 22.	55	16.36	96	1.020	1,060

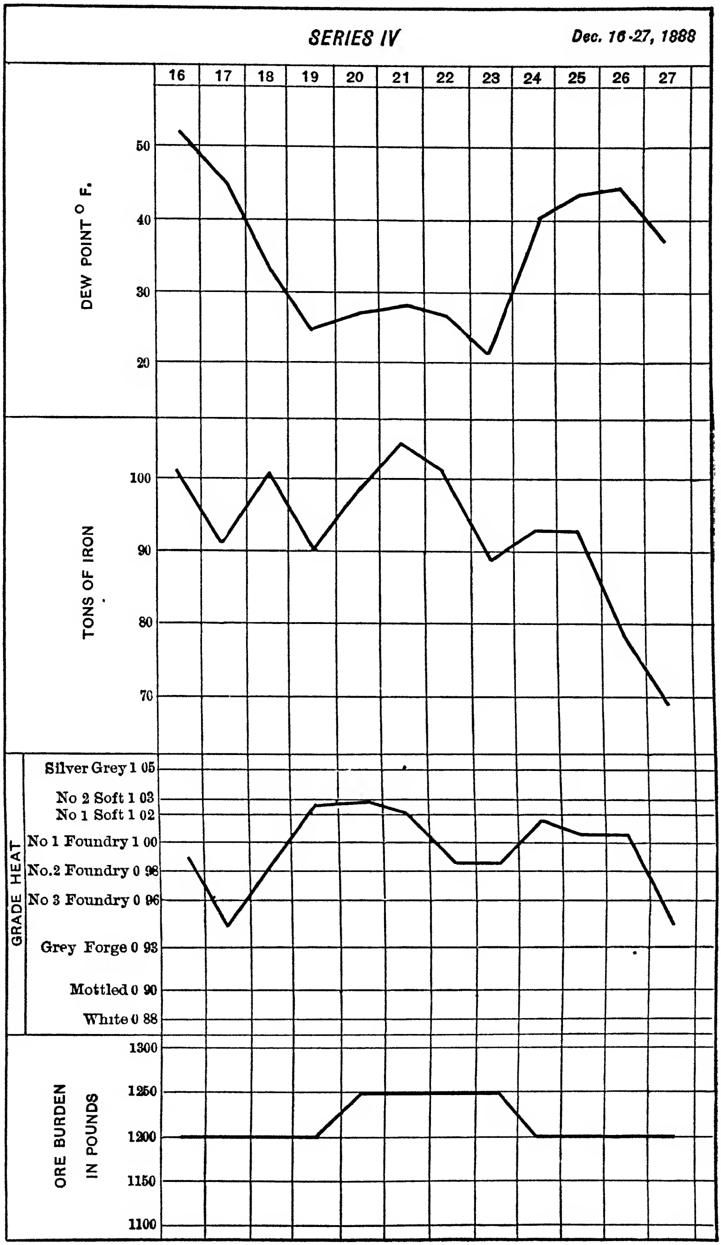
	1890.					
XI.	Jan. 9.	41	9.89	91	0.967	1,050
	Jan. 10.	55	16.22	96	0.949	1,050
	Jan. 11.	59	17.07	94	0.923	1,050
	Jan. 12.	56	16.33	91	0 930	1,025
	Jan. 13.	39	8.81	83	0.952	1,025
	Jan. 14.	40	9.78	104	0.962	1,025
	Jan. 15.	50	13.53	97	0.985	1,050
	Jan. 16.	26	5.64	95	0.952	1,050
	Jan. 17.	30	6.80	102	0.971	1,050
	Jan. 18.	34	7.88	95	0.988	1,050
	Jan. 19.	53	15.56	92	0.973	1,050
XII.	Jan. 20.	56	16.48	93	0.956	1,050
	Jan. 21.	37	18.87	96	0.983	1,050
	Jan. 22.	27	5.88	93	0.945	1,060
	Jan. 23.	37	8.79	105	0.990	1,060
	Jan. 24.	32	6.71	90	0.932	1,060
	Jan. 25.	40	8.58	95	0.940	1,060
	Jan. 26.	54	14.84	93	0.948	1,060
	Jan. 27.	50	12.92	95	0.955	1,060
	Jan. 28.	38	8.62	92	0 995	1,060
	Jan. 29.	43	9.79	78	0.974	1,075
	Jan. 30.	45	10.73	104	0.965	1,075
	Jan. 31.	50	12.67	102	0 957	1,075
XIII.	Feb. 15.	43	11.04	96	0.981	1,100
	Feb. 16.	45	12.30	108	0.977	1,100
	Feb. 17.	48	13.14	92	0 970	1,100
	Feb. 18.	55	16 80	102	0.970	1,100
	Feb. 19.	60	18.69	102	0.939	1,050
	Feb. 20.	38	8 62	108	0.914	1,060
	Feb. 21.	33	7.36	100	0.960	1,070
	Feb. 22.	33	7.89	98	1.000	1,070
	Feb. 23.	45	11.87	96	0 954	1,070
	Feb. 24.	61	20.78	100	0.993	1,070
	Feb. 25.	65	22 68	93	0.951	1,035
	Feb. 26.	63	21.82	84	0.947	1,035
XIV.	Feb. 27.	63	20.48	100	0.936	1,035
	Feb. 28.	44	11.55	117	0.937	1,200
	Mar. 1.	18	4 10	130	0.978	1,200
	Mar. 2.	19	4 05	111	0.978	1,200
	Mar. 3.	31	6.40	80	0.915	1,200
	Mar. 4.	36	8 26	95	0 928	1,200
	Mar. 5.	39	8.94	92	0.943	1,200
	Mar. 6.	27	5 88	91	0 973	1,200
	Mar. 7.	28	6.15	91	0 945	1,200
	Mar. 8.	31	6.89	98	0.949	1,150
	Mar. 9.	34	7.73	100	0.974	1,150
	Mar. 10.	45	11.35	91	1.007	1,150
	Mar. 11.	53	15.56	94	0 987	1,150
	Mar. 12.	58	17.46	92	0.966	1,150
XV.	Apr. 23.	58	17.14	93	0.917	1,075
	Apr. 24.	64	21.15	92	0.967	1,050
	Apr. 25.	65	21.86	88	0.911	1,050
	Apr. 26.	61	18.98	99	0.911	1,050
	Apr. 27.	52	14.75	81	0.937	1,050
	Apr. 28.	48	13.18	95	0.941	1,050
	Apr. 29.	51	14.37	99	0.977	1,050
	Apr. 30.	57	17.19	104	0.963	1,025
	May 1.	58	16.82	93	0.936	1,025
	May 2.	59	17.74	91	0.956	1,025
	May 3.	60	18.52	90	0.979	1,000
	May 4.	63	21.82	96	1.002	1,000
	May 5.	62	22.21	91	1.013	1,000

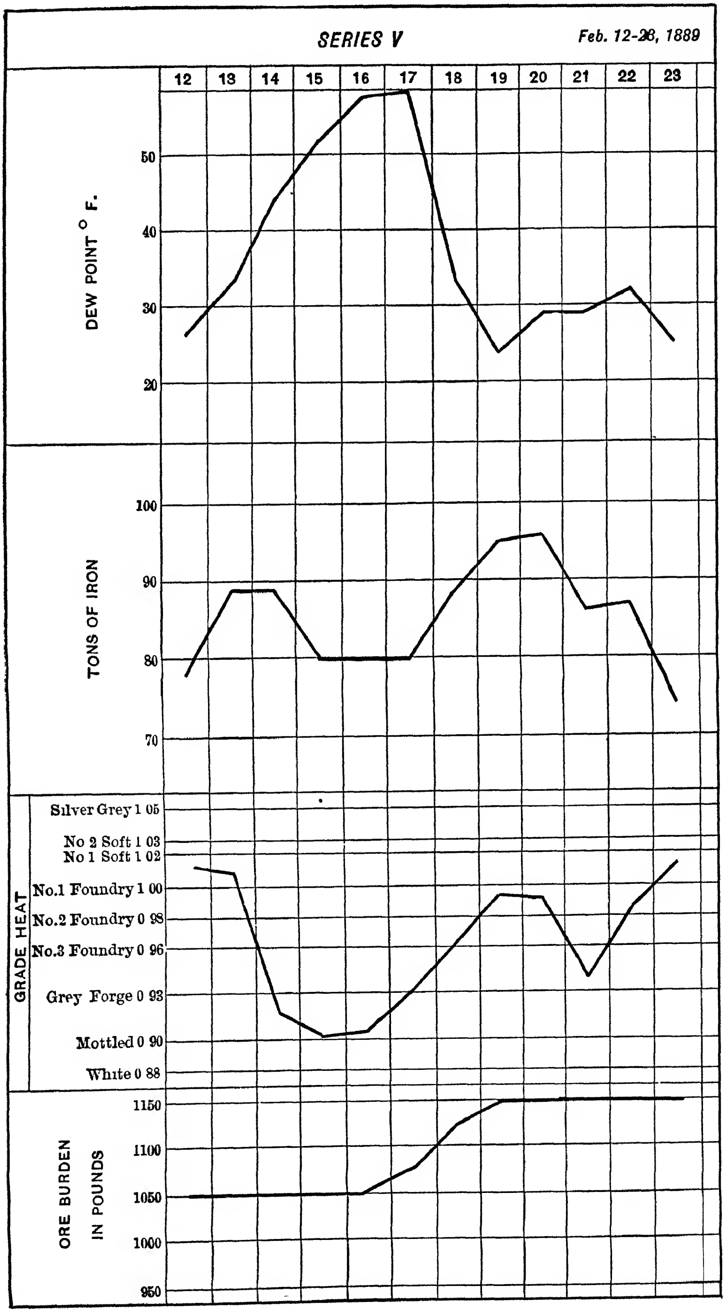
XVI.	June 1.	64	21.75	90	0.960	1,000
	June 2.	68	25.46	85	0.950	1,000
	June 3.	66	24.08	91	0.980	1,000
	June 4.	69	27.47	83	0.963	1,000
	June 5.	69	27.87	87	0.960	1,000
	June 6.	68	26.36	87	0.981	1,000
	June 7.	61	20.60	90	0.960	1,050
	June 8.	65	23.29	91	0.989	1,050
	June 9.	69	26.54	91	0.970	1,050
	June 10.	70	26.43	88	0.962	1,050
	June 11.	70	28.12	91	1.002	1,050
	June 12.	66	23.44	87	0.952	1,050
	June 13.	70	28.12	90	0.967	1,050
	June 14.	70	27.39	89	0.982	1,025

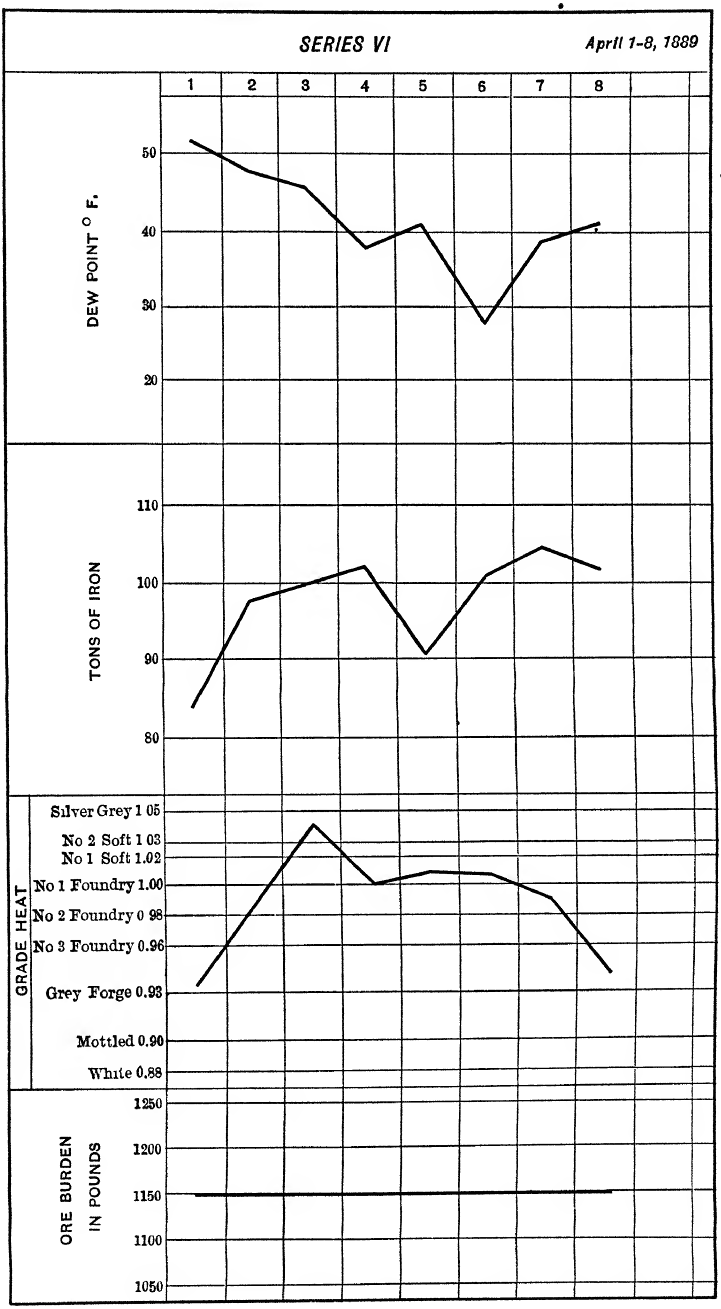

SERIES I
Aug. 20-31, 1888
20
21
22
23
24
25
26
27
28
29
30
31
DEW POINT ° F.
81
71
61
51
TONS OF IRON
88
78
68
58
GRADE HEAT
Silver Grey 1 05
No.2 Soft 1 03
No 1 Soft 1 02
No.1 Foundry 1 00
No 2 Foundry 0 98
No 3 Foundry 0.95
Grey Forge 0 93
Mottled 0 90
White 0 88
ORE BURDEN IN POUNDS
1150
1100
1050
1000
950

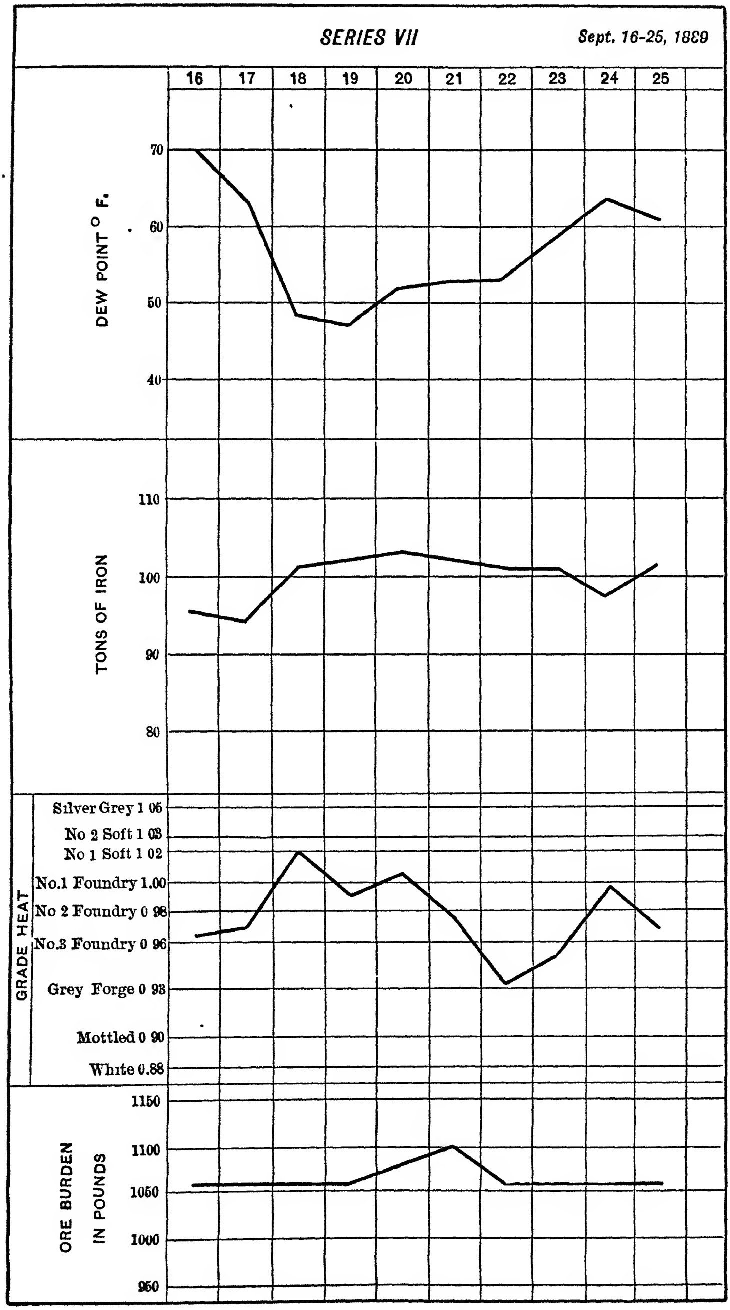

SERIES II
Sept. 22-Oct. 5, 1888
22 23 24 25 26 27 28 29 30 1 2 3 4 5
DEW POINT ° F.
64
54
TONS OF IRON
99
89
79
69
59
49
GRADE HEAT
Silver Grey 1 05
No 2 Soft 1 03
No 1 Soft 1 02
No.1 Foundry 1.00
No.2 Foundry 0 98
No.3 Foundry 0.96
Grey Forge 0.93
Mottled 0 90
White 0 88
ORE BURDEN IN POUNDS
1150
1100
1050
1000
950

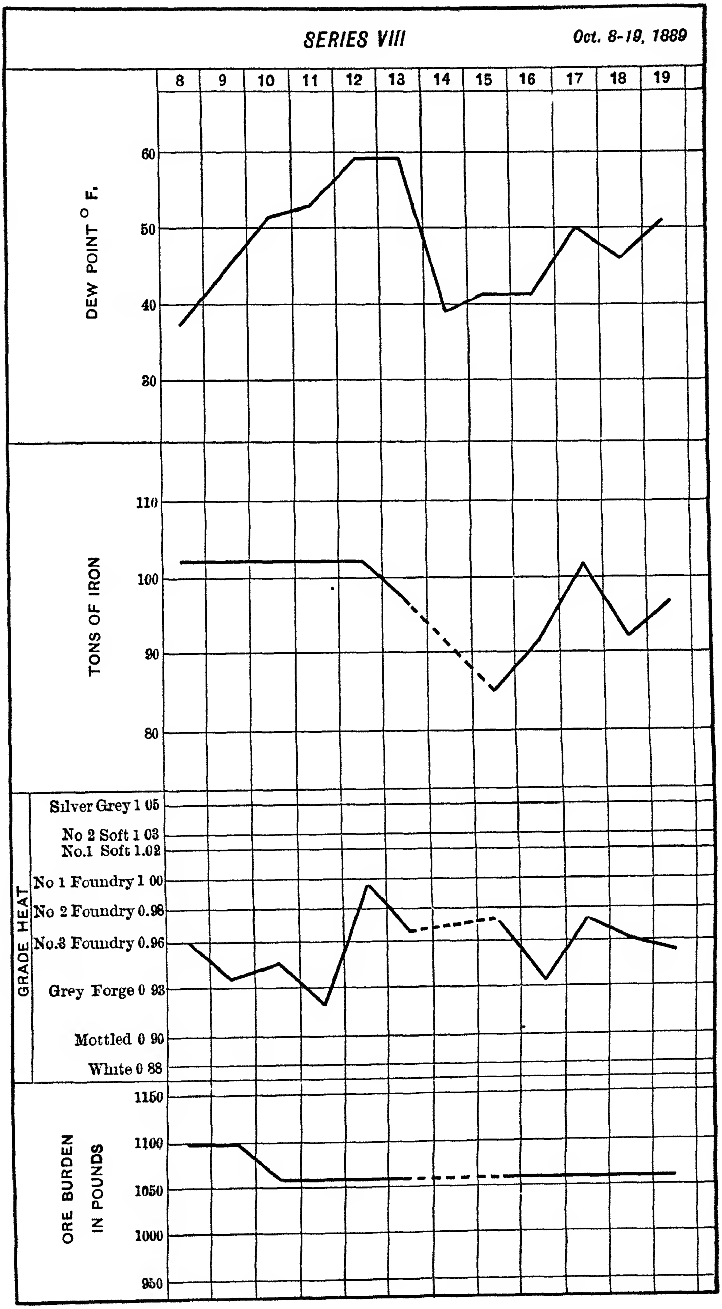

SERIES III
Oct. 27-Nov. 6, 1888
27
28
29
30
31
1
2
3
4
5
6
DEW POINT ° F.
68
58
48
38
TONS OF IRON
110
100
90
80
GRADE HEAT
Silver Grey 1.05
No 2 Soft 1.03
No 1 Soft 1.02
No 1 Foundry 1 00
No.2 Foundry 0 98
No.3 Foundry 0 96
Grey Forge 0 93
Mottled 0 90
White 0 88
ORE BURDEN IN POUNDS
1300
1250
1200
1150
1100

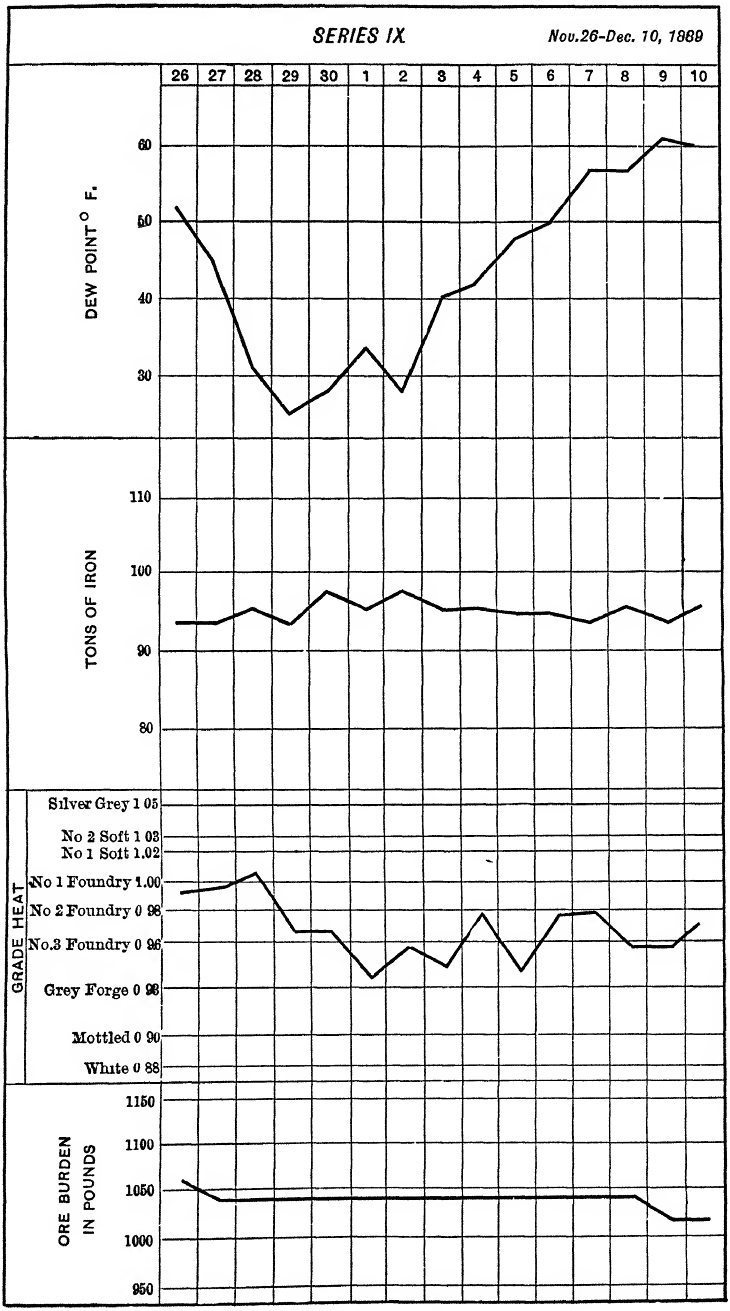

SERIES IV
Dec. 16-27, 1888
16
17
18
19
20
21
22
23
24
25
26
27
DEW POINT ° F.
50
40
30
20
TONS OF IRON
100
90
80
70
GRADE HEAT
Silver Grey 1 05
No 2 Soft 1 03
No 1 Soft 1 02
No 1 Foundry 1 00
No.2 Foundry 0 98
No 3 Foundry 0 96
Grey Forge 0 93
Mottled 0 90
White 0 88
ORE BURDEN IN POUNDS
1300
1250
1200
1150
1100

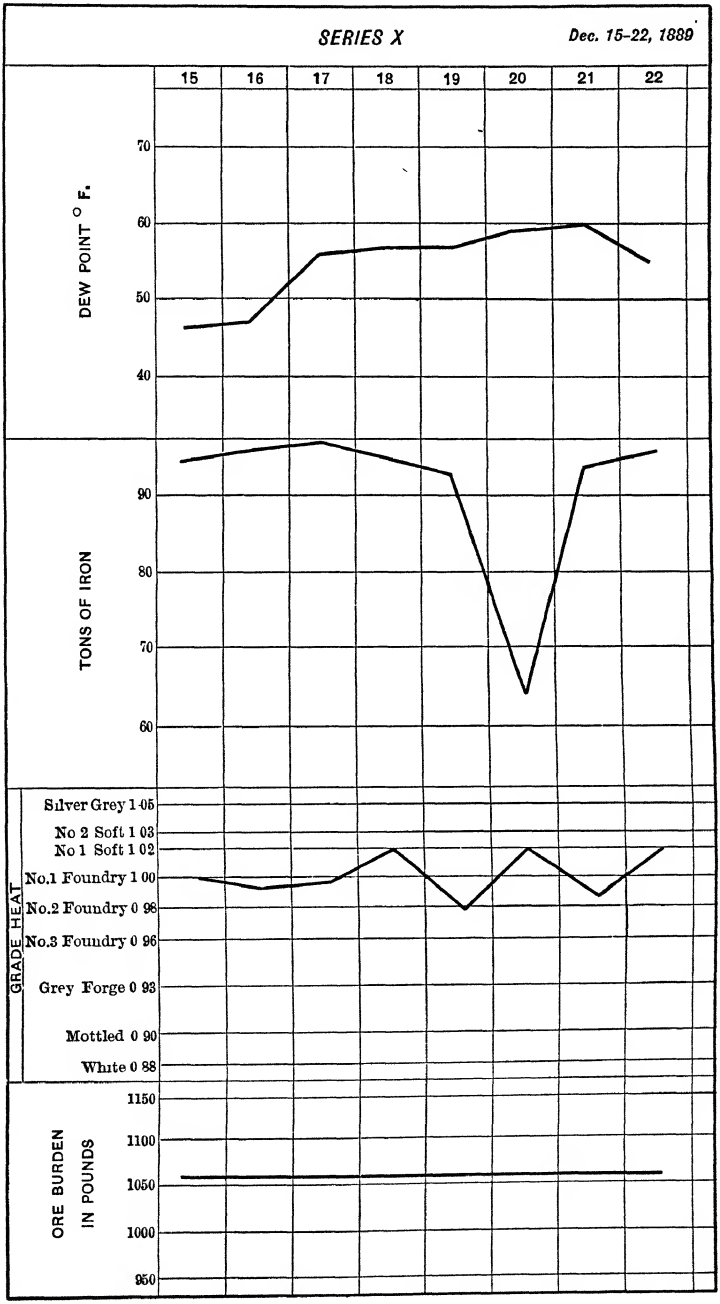

SERIES V
Feb. 12-28, 1889
12
13
14
15
16
17
18
19
20
21
22
23
DEW POINT ° F.
50
40
30
20
TONS OF IRON
100
90
80
70
GRADE HEAT
Silver Grey 1 05
No 2 Soft 1 03
No 1 Soft 1 02
No.1 Foundry 1 00
No.2 Foundry 0 98
No.3 Foundry 0 96
Grey Forge 0 93
Mottled 0 90
White 0 88
ORE BURDEN
IN POUNDS
1150
1100
1050
1000
950

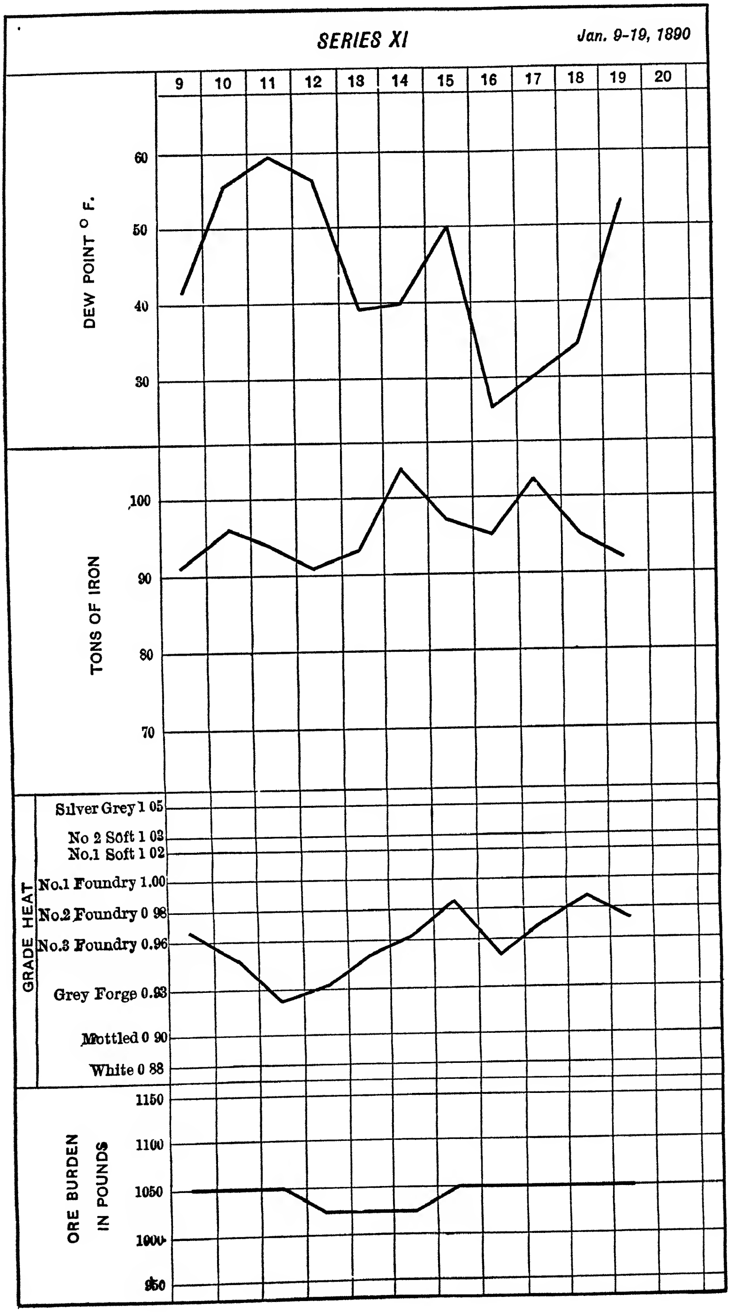

SERIES VI
April 1-8, 1889
1
2
3
4
5
6
7
8
DEW POINT ° F.
50
40
30
20
TONS OF IRON
110
100
90
80
GRADE HEAT
Silver Grey 1 05
No 2 Soft 1 03
No 1 Soft 1.02
No 1 Foundry 1.00
No 2 Foundry 0 98
No 3 Foundry 0.96
Grey Forge 0.93
Mottled 0.90
White 0.88
ORE BURDEN IN POUNDS
1250
1200
1150
1100
1050

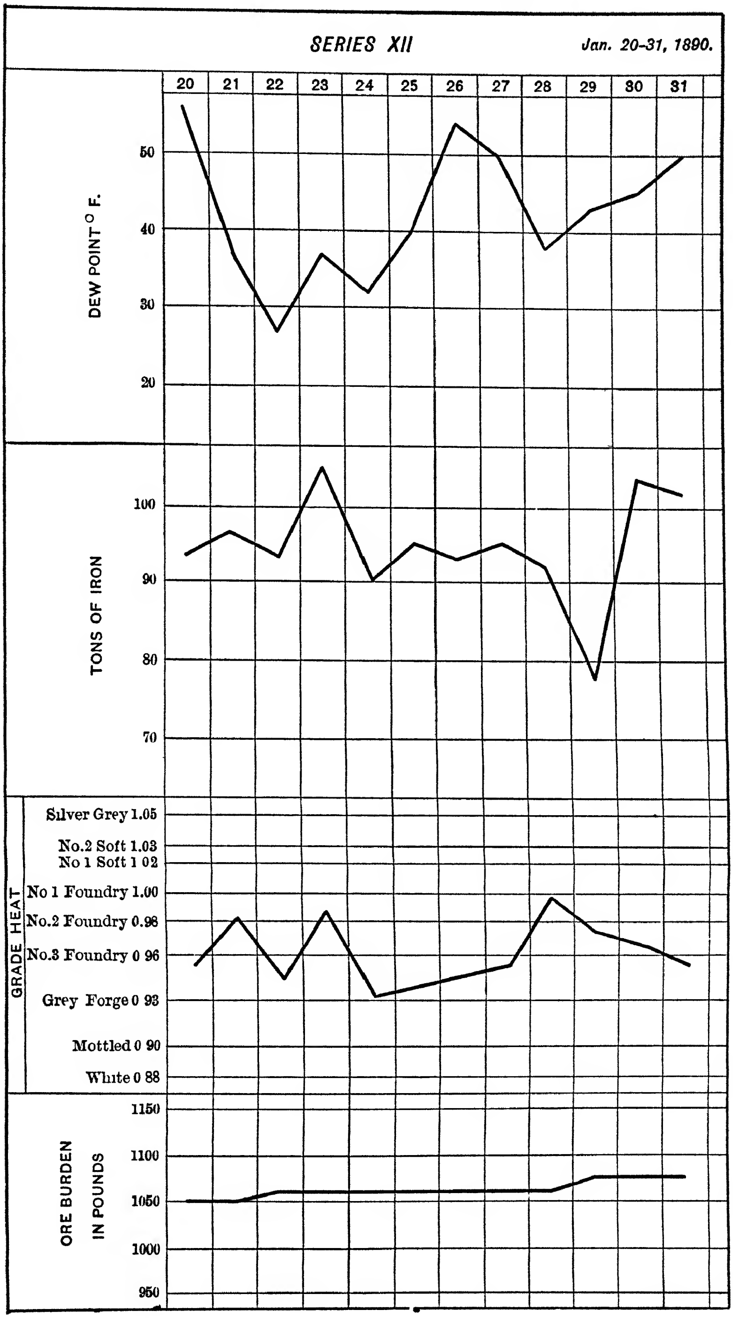

SERIES VII
Sept. 16-25, 1889
16 17 18 19 20 21 22 23 24 25
DEW POINT ° F.
70
60
50
40
TONS OF IRON
110
100
90
80
GRADE HEAT
Silver Grey 1 05
No 2 Soft 1 03
No 1 Soft 1 02
No.1 Foundry 1.00
No 2 Foundry 0 98
No.3 Foundry 0 96
Grey Forge 0 93
Mottled 0 90
White 0.88
ORE BURDEN IN POUNDS
1150
1100
1050
1000
950

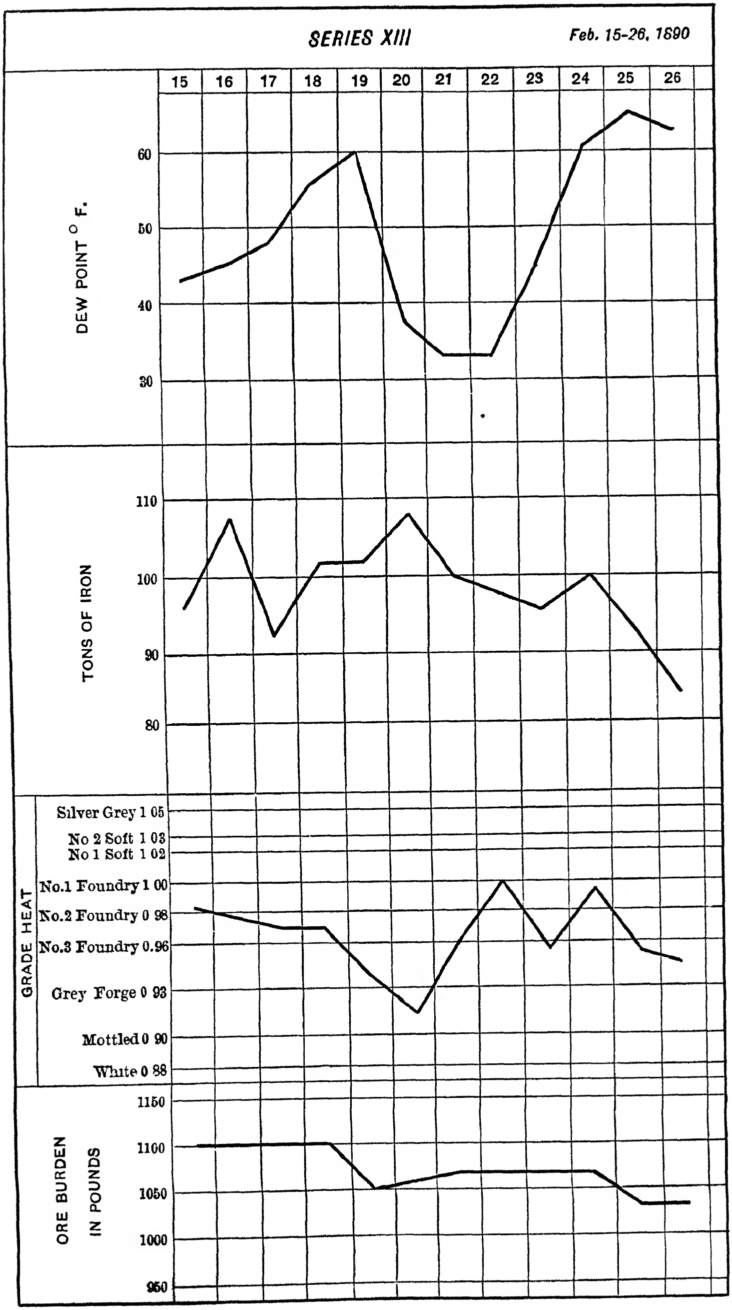

SERIES VIII
Oct. 8-19, 1889
8
9
10
11
12
13
14
15
16
17
18
19
DEW POINT ° F.
60
50
40
30
TONS OF IRON
110
100
90
80
GRADE HEAT
Silver Grey 1 05
No 2 Soft 1 03
No.1 Soft 1.02
No 1 Foundry 1 00
No 2 Foundry 0.98
No.3 Foundry 0.96
Grey Forge 0 93
Mottled 0 90
White 0 88
ORE BURDEN IN POUNDS
1150
1100
1050
1000
950

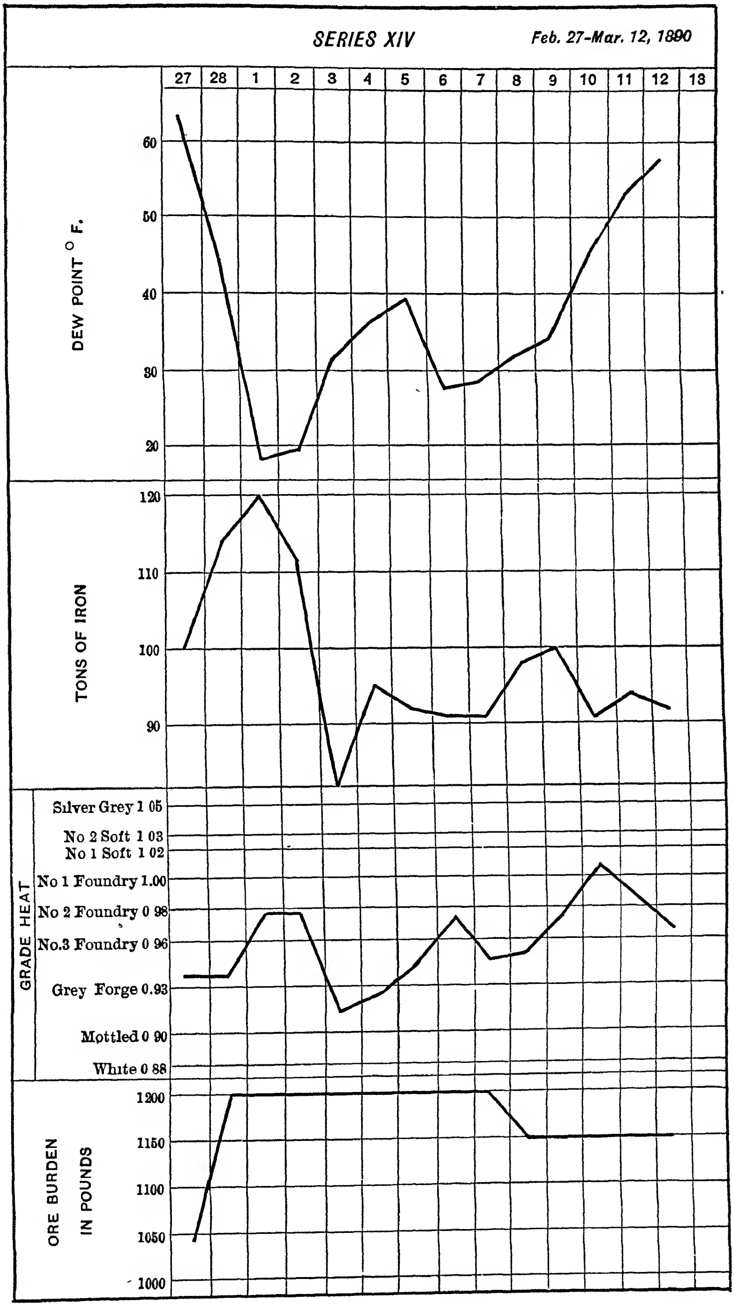

SERIES IX
Nov.26-Dec. 10, 1889
26 27 28 29 30 1 2 3 4 5 6 7 8 9 10
DEW POINT ° F.
60
50
40
30
TONS OF IRON
110
100
90
80
GRADE HEAT
Silver Grey 1 05
No 2 Soft 1 03
No 1 Soft 1.02
No 1 Foundry 1.00
No 2 Foundry 0 98
No.3 Foundry 0 96
Grey Forge 0 93
Mottled 0 90
White 0 88
ORE BURDEN IN POUNDS
1150
1100
1050
1000
950

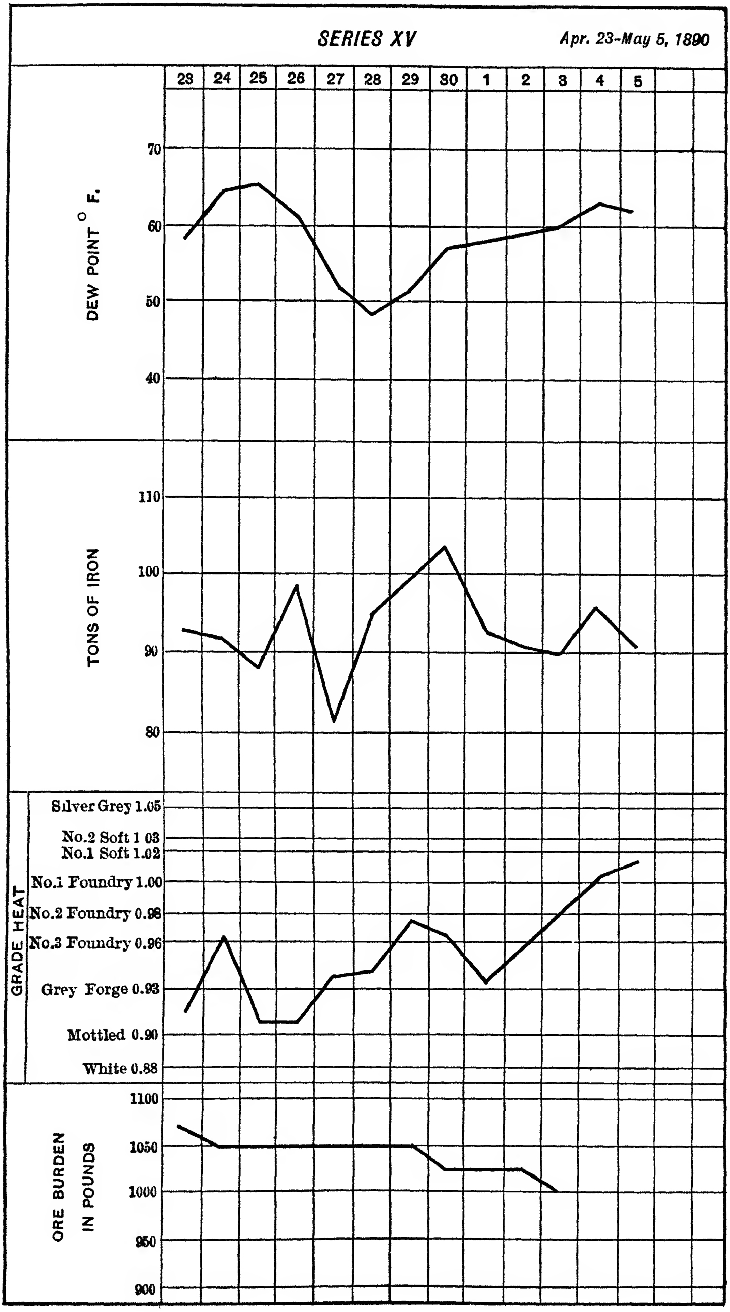

SERIES X
Dec. 15-22, 1889
15
16
17
18
19
20
21
22
DEW POINT ° F.
70
60
50
40
TONS OF IRON
90
80
70
60
GRADE HEAT
Silver Grey 1 05
No 2 Soft 1 03
No 1 Soft 1 02
No.1 Foundry 1 00
No.2 Foundry 0 98
No.3 Foundry 0 96
Grey Forge 0 93
Mottled 0 90
White 0 88
ORE BURDEN IN POUNDS
1150
1100
1050
1000
950

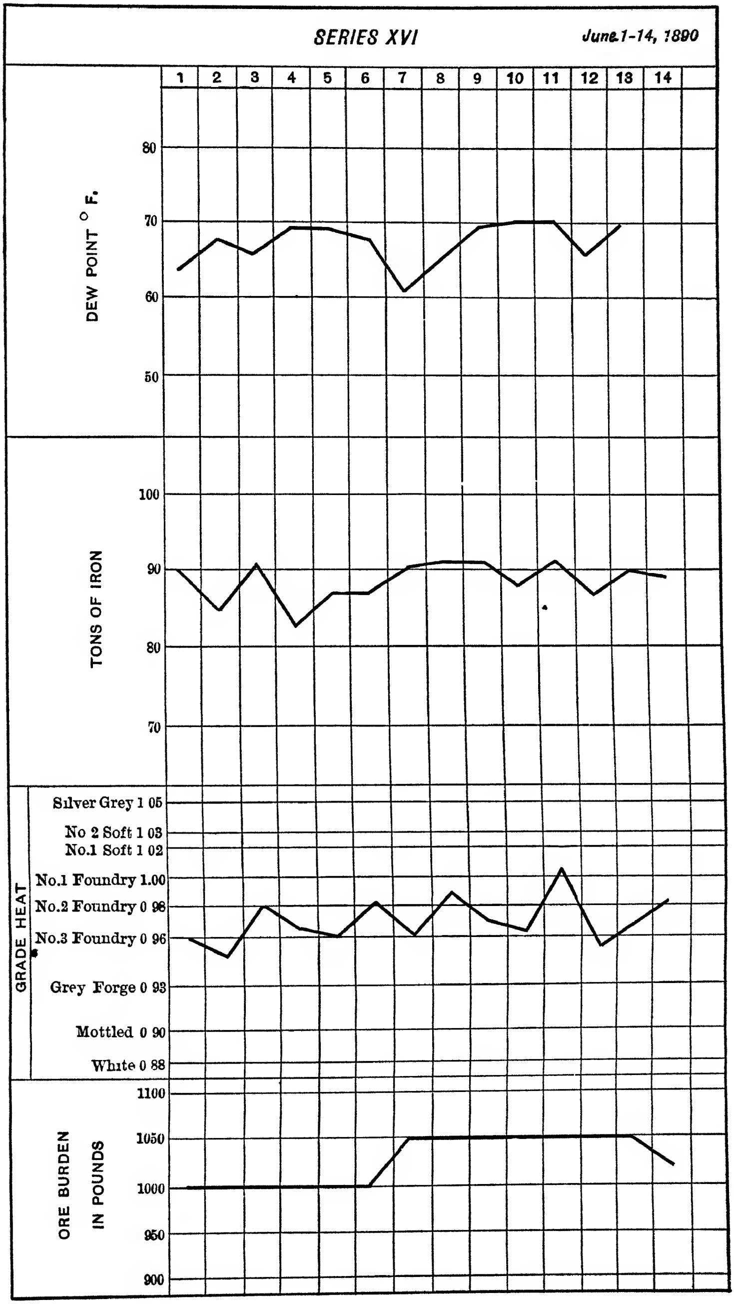

SERIES XI
Jan. 9-19, 1890
9
10
11
12
13
14
15
16
17
18
19
20
DEW POINT ° F.
60
50
40
30
TONS OF IRON
100
90
80
70
GRADE HEAT
Silver Grey 1 05
No 2 Soft 1 03
No.1 Soft 1 02
No.1 Foundry 1.00
No.2 Foundry 0 98
No.3 Foundry 0.96
Grey Forge 0.93
Mottled 0 90
White 0 88
ORE BURDEN IN POUNDS
1150
1100
1050
1000
950


SERIES XII
Jan. 20-31, 1890.
20 21 22 23 24 25 26 27 28 29 30 31
DEW POINT ° F.
50
40
30
20
TONS OF IRON
100
90
80
70
GRADE HEAT
Silver Grey 1.05
No.2 Soft 1.03
No 1 Soft 1 02
No 1 Foundry 1.00
No.2 Foundry 0.98
No.3 Foundry 0 96
Grey Forge 0 93
Mottled 0 90
White 0 88
ORE BURDEN IN POUNDS
1150
1100
1050
1000
950


SERIES XIII
Feb. 15-26, 1890
15
16
17
18
19
20
21
22
23
24
25
26
DEW POINT ° F.
60
50
40
30
TONS OF IRON
110
100
90
80
GRADE HEAT
Silver Grey 1 05
No 2 Soft 1 03
No 1 Soft 1 02
No.1 Foundry 1 00
No.2 Foundry 0 98
No.3 Foundry 0.96
Grey Forge 0 93
Mottled 0 90
White 0 88
ORE BURDEN
IN POUNDS
1150
1100
1050
1000
950


SERIES XIV
Feb. 27-Mar. 12, 1890
27 28 1 2 3 4 5 6 7 8 9 10 11 12 13
DEW POINT ° F.
60
50
40
30
20
TONS OF IRON
120
110
100
90
GRADE HEAT
Silver Grey 1 05
No 2 Soft 1 03
No 1 Soft 1 02
No 1 Foundry 1.00
No 2 Foundry 0 98
No.3 Foundry 0 96
Grey Forge 0.93
Mottled 0 90
White 0 88
ORE BURDEN IN POUNDS
1200
1150
1100
1050
1000


SERIES XV
Apr. 23-May 5, 1890
23 24 25 26 27 28 29 30 1 2 3 4 5
DEW POINT ° F.
70
60
50
40
TONS OF IRON
110
100
90
80
GRADE HEAT
Silver Grey 1.05
No.2 Soft 1 03
No.1 Soft 1.02
No.1 Foundry 1.00
No.2 Foundry 0.98
No.3 Foundry 0.96
Grey Forge 0.93
Mottled 0.90
White 0.88
ORE BURDEN IN POUNDS
1100
1050
1000
950
900


SERIES XVI
June 1-14, 1890
1
2
3
4
5
6
7
8
9
10
11
12
13
14
DEW POINT ° F.
80
70
60
50
TONS OF IRON
100
90
80
70
GRADE HEAT
Silver Grey 1 05
No 2 Soft 1 03
No.1 Soft 1 02
No.1 Foundry 1.00
No.2 Foundry 0 98
No.3 Foundry 0 96
Grey Forge 0 93
Mottled 0 90
White 0 88
ORE BURDEN IN POUNDS
1100
1050
1000
950
900

Blast-Furnace Practice.*

A Discussion of the papers of James Gayley, on "The Application of Dry-Air Blast to the Manufacture of Iron" (see *Trans.*, xxxv., 746, 1022, also pp. 315 and 745 of the present volume, and of J. E. Johnson, Jr., on "The Physical Action of the Blast-Furnace," p 454.

CHAS. B. DUDLEY, Altoona, Pa.:—I am not a blast-furnace man, and this always puts me at a disadvantage because I cannot go into the details of the making of iron and steel. I have not the experience, and have to take the statements of other people, so what I say regarding the subject of this paper is not in the sense of an expert.

When I first heard of Mr. Gayley's experiments, I said to myself, "I fear they will result in failure, since, apparently, Mr. Gayley has forgotten one chemical fact, namely, that carbon does not combine with oxygen in the absence of water-vapor." This fact which was so astonishing when it was first brought out some years ago, and which those who are interested may find in the *Journal of the Chemical Society of London*, for 1885, page 349, and 1894, page 611, led me to think that the drying of the air would be a mistake. The general subject of the influence of water-vapor on chemical action is a large one; but the special point in which we are, for the moment, interested, namely, the influence of water-vapor on the combustion of carbon, was especially treated by Mr. H. B. Baker, in the papers referred to. Apparently, however, as the result of Mr. Gayley's experiments, we are to learn that the amount of moisture still left in the desiccated air is sufficient to secure perfectly satisfactory combustion.

In thinking over Mr. Gayley's paper, it occurred to me that there were two alternatives, either of which might be chosen, namely, we might dry the air as Mr. Gayley does, or possibly we might, in a very much easier way, simply saturate the air at a constant temperature, and thus get uniform working and

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* Presented orally at the Washington Meeting, May, 1905.

satisfactory results. I had even gone so far, in my mind, as to plan some experiments on cupola-practice, in which I proposed simply to saturate the air at a constant temperature. But now, in view of the paper which we have just heard from Mr. Johnson, it looks as though those experiments would have been failures; or, at least, as though the introduction of air saturated with moisture at constant temperature, into either the blast-furnace, or the cupola, would result in a diminution of the available heat above critical temperature, and consequently a diminution in economy. I am now accordingly inclined to wait awhile, before attempting any experiments on the use of saturated air on cupola-melting.

It may not be amiss to add, that the influence of saturated air on the volume of combustible gases, obtained from the top of the cupola or top of the blast-furnace, may be a feature which is worth exploiting a little farther, before the final word is said on this subject.

Those of us, who are struggling to keep up with the progress of knowledge in the great field of chemistry, know that one of the most live features of the subject, at present, is physical chemistry; and I recently found this question of the influence of moisture on chemical change quite elaborately discussed in one of the recent works on physical chemistry.

R. W. Raymond, New York, N. Y.:—Mr. Johnson's distinction between the heat required to produce and maintain the working-temperature, or what he calls the "critical" temperature, and the additional heat required for the operation itself—or what he calls the "available" heat—is well-taken, and seems to be a new point in the discussion of the thermal economy of the blast-furnace. If we put into a furnace x heat-units for the first purpose, and y for the second, the work done depends upon y, and to double that work we would only have to double y. In other words, we would need $x + 2y$, not $2x + 2y$, heat-units.

I would like to ask whether, in Mr. Johnson's experiments, account was taken of diurnal variations in atmospheric moisture. In Mr. Gayley's original paper, these were shown to have a considerable range and influence.

J. E. JOHNSON, JR., Longdale, Va.:—In my experiments, the diurnal variations were very small, and were not taken into account. The moisture in the engine-room comes from little leaks of steam, and the fluctuations are as great as they are outside. On the whole, there is a great advantage in taking the air from the outside. So far as I know, Mr. Gayley was the first in this country to adopt this. In our last installation at Longdale, the engine-house was planned with a view to taking the air from the outside.

WILLIAM F. MATTES, Scranton, Pa.:—I would like to ask if Mr. Gayley's experiments have been pushed to the point where he was able to make any estimates on the commercial value of his process of desiccating the blast. I thought it probable that the experiments had not reached a stage where such calculations, even in a preliminary way, could be made.

MR. GAYLEY:—I might say that there is one point brought out in my former paper in regard to the statement that a great deal of expense was incurred in operating the dry-air blast. If you will refresh your memory by reviewing that paper, you will see that the saving in horse-power practically compensates for the expenditure of power in dry blast. As regards the cost, there is an increase in the production, and there is economy in fuel, which vary with every locality. There is also an increase in the product and a saving of fuel. These are items the money-value of which varies with every locality; and all I can do is to leave it to your judgment, and say, that, each for his own particular section, must work it out for himself.

MR. MATTES:—It seems to me that there is one feature of it which, in practice, even if it did not show up very clearly in daily economy, would make the apparatus valuable, and that is the additional control—something like the difference between driving a horse with one rein or with two.

DAVID BAKER, Philadelphia, Pa.:—I am greatly interested in Mr. Johnson's paper. It seems to me that he has "gotten the meat out of the cocoanut." It does not seem strange to me that the saving which Mr. Gayley records has been found to be an actual fact in the operation of the furnace with this dry-

blast apparatus. I have always appreciated the value of dry blast, and, about ten years ago, I made some experiments on the humidity of the atmosphere inside the engine-house and outside, not knowing at the time that anyone else was doing the same work. I found that the atmosphere inside the engine-house had twice as much moisture as the outside, and subsequently making a trip to Pittsburg I called on Mr. Gayley and found that he had had the same experience, and had applied for a patent for drying the atmosphere for blast-furnaces.

About that time, at the plant of the Maryland Steel Co., I decided to take advantage of the outside air, and built a wooden flume or air-box to convey the outside air to one of the blowing-engines, and connected it with the inlet-valves. The connection was the best that could be made for a small outlay. As the engine was not designed for such an arrangement there were a good many leaky joints. One of the great changes that we noticed, however, was that, whereas we used to burn out our leathers on the inlet-valves every month, with the new connection our leathers would last three months, showing that the air coming in was much cooler, and we figured a considerable increase in the blowing-capacity of the engine.

One great point which Mr. Johnson brings out, is illustrated in modern installations of electric power, and that is the means of "taking care of the peaks of the load." In the blast-furnace data before us, I notice that Mr. Gayley gets a higher blast-temperature with the furnace when he uses dry blast. This, I think, is due to the fact that, in the usual furnace-practice, the blast-furnace manager has found it necessary to carry reserve heat somewhere to take care of the "peaks of the load," or, in other words, so he will not be called up at midnight with advice from his foundryman that the cinder is too cold to run. I think what Mr. Gayley has done in obtaining this uniformity in the humidity of the blast is to prevent "the peaks of the load," and I believe that future progress in blast-furnace work, and in the economy resulting therefrom, will be obtained by looking after all the details of such work (many of which have heretofore been neglected) and to render all the conditions of furnace-practice as uniform as possible. When this is accomplished, the manager will not carry so much reserve heat. He will "sail closer to the wind," and the result

will be a saving of fuel in the entire operation. I would like to ask Mr. Gayley if, during his experiment at Isabella, he ever noticed, on the part of a manager, any hesitancy about cutting-down the reserve heat, which he ought to be able to do with the dry-blast system?

Mr. Gayley:—The manager tried to run up to his limit.

John Birkinbine, Philadelphia, Pa.:*—Mr. Gayley was not the only blast-furnace manager investigating the possibilities of dry air as applied to the smelting of iron-ores, and I understand he makes no claim to such distinction. It was my privilege to be familiar with some of the earlier efforts in this direction, and the persistency with which Mr. Gayley has followed the subject. Whatever, therefore, may come from the practical application of dry air, may be credited to protracted investigation, and a conscientious study of the possibilities.

This special feature of blast-furnace economy is an evidence of the general policy which has done so much in the last quarter of a century to make the smelting of iron-ores more than a mere "rule of thumb." Within my professional experience, the manager who desired a greater output would construct a furnace of larger dimensions, and with more powerful equipment; but, in later years, improvements have not been confined to physical conditions, but have resulted from chemical research and the perfection of mechanical appliances. Mr. Johnson's paper is a valuable contribution to these researches.

Former blast-furnace records covered the number and size of charges, the pressure and temperature of blast, etc., as taken several times a day. Now, the story of blast-furnace operation is practically a continuous one. The chemical composition of the ore, fuel and flux is constantly before the manager; the volume, pressure and temperature of blast are matters of continuous record; and the conditions at the top of the furnace are, in some cases, similarly reported.

In studying the operations of a blast-furnace, all of the above are of assistance; for, otherwise, conclusions may be based on

* [Secretary's Note.—This report of Mr. Birkinbine's remarks is here printed as a substitute for the version contained in the *Bi-Monthly Bulletin* for September, 1905, p. 1151, which was published without opportunity of revision. —R. W. R.]

erroneous data. As an instance, we find that much of the irregularity in the operation of some of the larger blast-furnaces is credited to the large amount of fine ore fed into them, an amount in most cases certainly more than was charged in earlier practice. But we omit to give consideration to the fact that, owing to the method of supplying the raw material to blast-furnaces through bins, scale hopper-cars, self-dumping skips, double bells, etc., and by dropping from one receptacle to another, all the raw materials are more comminuted by abrasion. As a result, there is received at the top of the furnace not only fine ore, and more or less fine limestone, but a larger amount of finely-comminuted coke, which may become incandescent, but cannot be consumed until the oxygen of the blast reaches it; when the reaction may be so intense as to produce explosions similar to those which occur in dry coal-mines, grain-elevators, flour-mills, etc., where finely divided carbon in air meets with a spark or flame.

Mr. Johnson's paper offers an interesting field for future research; and he is to be congratulated on the manner in which he has collected the data, and thanked for bringing them before the Institute, where they will invite a wide discussion.

F. E. Bachman, Port Henry, N. Y.:—Fine ores do not necessarily give special trouble in the blast-furnace. At present, 90 per cent. of the mixture used in the Northern Iron Co.'s furnace is magnetic ore which will pass a 4-mesh sieve. It made over 98 per cent. of standard basic iron during the 4 months ending May 1, 1905, on an average fuel-consumption of 2,241 lb., using 26 per cent. of anthracite coal and 74 per cent. of mountain coke. For a period of 90 days, it did not make a cast other than standard basic. The furnace is 10 ft. hearth, 17 ft. bosh, and 69 ft. 3 in. high. We are now designing and building a furnace in which we expect to use 100 per cent. of magnetic concentrate, passing a 6-mesh sieve, 30 per cent. of which will pass a 60-mesh sieve. We do not know whether we will have trouble with this material or not, but we do not expect much more than the ordinary irregularities of furnace working.

When using fine ores, especially granular magnetic concentrates, the secret of success seems to be proper distribution.

This condition, we think we have attained, by the use of a slight modification of Mr. Firmstone's modified Langon charger.

Explosions which have generally been attributed to the use of fine ores are caused not from the fineness of the ore, but by some action of fine hematite-ores. Our furnace, which has been in operation for more than two years, has never made a puff of black smoke. The furnace which we are now rebuilding was operated as a charcoal-furnace, using 100 per cent. of magnetic concentrates the greater part of the time; although charcoal-furnaces are more likely to have top-explosions than coke-furnaces, it was always free from this class of trouble.

The Taviche Mining-District Near Ocotlan, State of Oaxaca, Mexico.

Discussion of the Paper of H. M. Chance (see *Trans.*, xxxv., 886).

EDWARD HALSE, Puerto Berrio, Colombia, So. Amer. (communication to the Secretary*): The Taviche mining-district is generally known as "Taviches," being named from the two villages called respectively San Pedro Taviche and San Jeronimo Taviche.

It is so called by José G. Aguilera, in his paper on the Geographical and Geological Distribution of the Mineral Deposits of Mexico;[1] and in published reports by the late N. W. Rudston Read;[2] and by Juan de Dios Villarello.[3]

The region is a large one, measuring about 24 miles long and 7 miles wide.

Dr. Chance, in his interesting paper, tells us very little about the nature of the ores, and, with regard to the geology of the district, contents himself with observing that "the country, as a rule, consists of eruptive rocks; and no evidences of sedimentary strata appear near the mines." The latter part of the above statement is hardly correct. The formation is mainly

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* Received January 10, 1905.

[1] *Trans.*, xxxii., 519 (1902).

[2] *Report on the Rosario Reduction Works, in the State of Oaxaca*, London, p. 20 (1886).

[3] *Informe relativa á la Region Minera de Taviches*, Mexico (1894).

eruptive, being hornblende-andesite of Tertiary age, which is limited on the east by the calcareous (Cretaceous) formation, and on the west by the Huronian rocks of Ocotlan. Limestone is seen close to the Santa Catarina mine, at the northern end of the region. In the surface-working known as La Cueva, a little northeast of San Pedro, limestone forms the eastern wall of the deposit which consists of spots (*moscas*) of pyrargyrite in white opaque or transparent quartz. In one place, the ore is associated with stibnite, and the quartz frequently exhibts a spherical radiated structure. An adit-level, driven some years ago below the above-named and other workings on the same line of fracture, is said to have penetrated limestone. This rock is no doubt of Cretaceous age, and will probably throw some light on the genesis of the ores.

I examined the Taviches district about ten years ago, on behalf of the Compañia Mexicana Explotadora y Beneficiadora de Menas Auriferas de Oaxaca, which, at that time, was opening up a number of claims, especially north of San Pedro; and, a few years later, I wrote a description of the district.[4]

Some peculiarities in the structure of the veins are given in my paper, Notes on the Structure of Ore-Bearing Veins in Mexico.[5]

The chief characteristics of the veins appear to be as follows:

1. The general strike of the principal veins is NW–SE., a southerly dip predominating. These are crossed by an older E–W. system of bedded veins.

2. The larger veins frequently have a number of curved branches on the foot-wall side, which unite in places, forming, at the outcrop, enormous "blows" of quartz, measuring, in some instances, several hundred feet across. Similar curved branches occur on the foot-wall side of the principal veins of Zacatecas and Guanajuato (*veta madre*), and may be present on either wall in Pachuca.

Parallel to these veins, there appears to be a number of felsite dikes—indeed, some of the larger lodes are probably dikes, which are strongly metalliferous in places.

3. The silver-ore consists mainly of pyrargyrite associated

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[4] Some Silver-Bearing Veins of Mexico, *Transactions of the Institution of Mining Engineers* (London), vol. xxiii., pp. 243–257, 1 folding plate (1899).

[5] *Trans.*, xxxii , 288, 294, 295, 301, Figs. 6, 16, 17 and 26 (1902).

occasionally with proustite, argentite and polybasite. Other associations are pyrite, galenite, stibnite, chalcopyrite and sphalerite. The matrix consists mainly of quartz; calcite and gypsum occur occasionally; fluorite and rhodonite are also said to have been found. Gold occurs in variable proportions; the percentage appears to increase northward, where *colorados* predominate. In the southern portion of the district sulphide ores are sometimes found from the surface downward.

4. The ore is usually distributed in the veins in ribs, or bands, separated by layers of altered country-rock; but sometimes the ore is in bunches, in small round masses (known in the district as *ruedas*) or as isolated shoots (*moscas*) in quartz.

5. The ore frequently occurs in small shoots, which cross the lode obliquely, and pitch in a southerly direction.

6. The roughly-banded structure is sometimes masked by a number of later-formed joints which cross the lode obliquely to the strike and have a southerly dip.

It is certain that the Spaniards worked the Santa Catarina or Cubilete, the Vichache and Rosario mines, situated at the northern end of the region, but it is very doubtful whether any of these mines were worked by the Aztecs or Toltecs.

Dr. Chance is somewhat severe on the Mexican miner. It is true that a number of mines have been worked by Mexicans in a very desultory and irregular manner—the *buscones*, however, are largely responsible for this. Centuries ago, the Mexicans brought ore-getting, at a minimum of cost and a maximum of instability in underground workings, to a fine art.

Mexican companies have for a number of years been successfully exploiting mines in Mexico, notably in Pachuca and Real del Monte, hence the statement of Dr. Chance that "the Mexican never blocks out ore-reserves" must be received with limitations.

It is satisfactory to know that foreign capital is invested in the district, for no doubt it will become an important one in the near future.

The Effect of Silver on the Chlorination and Bromination of Gold.

Discussion of the paper of H. O Hofman and M. G Magnuson (see *Trans.*, xxxv., 948).

T. KIRKE ROSE, London, Eng. (communication to the Secretary*) :—The authors have shown that, under certain conditions, the rate of dissolution of gold by chlorine and bromine is reduced by the addition of 10 per cent. of silver to the gold, and that the action is almost stopped when the silver amounts to 30 or 40 per cent. of the alloy. Even if full recognition is given to the practical way in which the work was done, however, it is to be regretted that Prof. Hofman and Mr. Magnuson did not determine the temperature at which the experiments were carried out. From the details given, it may be inferred that the temperature was raised by chemical action by about 20° C. when 21 g. of sulphuric acid was added, and that the mixture was then slowly cooled down during the experiment. When bromine or very weak chlorine solutions were used, there could not have been any perceptible heating-action. As the action of both chlorine and bromine is aided by heat, it follows that the stronger solutions of chlorine were given an unfair advantage over the weaker solutions, and over bromine. If the temperature had been the same in each case, I do not think that the conclusions deduced by Prof. Hofman and Mr. Magnuson[1] would have been found to be justified. (This is speaking generally. In barrel-treatment the conditions are similar to those in the experiments.) The superior speed of bromine as compared with chlorine at equivalent strengths is not yet disproved, and the differences noted between strong and weak solutions of chlorine may have been largely a function of the temperature.

Moreover, the authors used somewhat-coarse particles of gold, and did not try how far time was a factor, although it is obvi-

* Received May 25, 1905.

[1] *Trans.*, xxxv., 959, 960 (1905).

ous that coarse gold must dissolve slowly in dilute solutions whether it contains silver or not.

These are points of greater interest than may, at first sight, appear. The authors have furnished evidence, which, if valid, would tell in favor of barrel-chlorination with the use of super-saturated solutions, as against vat-chlorination (amended Munktell process) with the use of dilute solutions. In practice, the difference between these two processes seems to be mainly a matter of time. Ores are efficiently chlorinated in barrels in 5 or 6 hr. with a solution containing about 0.65 per cent. of chlorine (equal to 1 g. in the authors' experiments) and are successfully treated in vats in from 30 to 120 hr. with a solution containing about 0.13 per cent. of chlorine (equal to 0.2 g. in the authors' experiments).

It may be that the ores treated in barrels are not amenable to treatment in vats, but so far as I am aware, nothing has been published to substantiate this hypothesis. If the authors had paid due attention to temperature, and had tried the effect of time on the treatment, a decided step would have been taken towards solving the problem.

As it is, they have given an answer to the question they had set themselves, and have shown that the presence of 20 per cent. of silver in gold has about equally deleterious effects when solutions containing 0.87 per cent. of chlorine and 0.14 per cent. of chlorine, respectively, are used, the rate of solution of gold being reduced in each case by about one-half. It also appears that, subject to revision when the difference of temperature is adjusted, a solution containing 0.87 per cent. of chlorine dissolves gold about three times as fast as one containing 0.14 per cent. of chlorine.

H. O. Hofman, Boston, Mass. (communication to the Secretary*):—In chlorinating and brominating silver-bearing gold-ores in revolving barrels, it is found that comparatively little silver is extracted, and it is believed that the silver has a harmful influence upon the yield of the gold. It is this belief which prompted us to undertake the work. As our paper shows, we confined our attention to barrel-work and tried to imitate the large-scale conditions, as far as possible, in a series of labora-

* Received October 19, 1905.

tory experiments with the two variables;—concentration of solutions and percentages of silver. We did not attempt to solve the purely chemical question of the relative solubility of gold in chlorine and bromine, but had to consider, incidentally, one phase of it in making the start of our alloy-series with pure gold. A determination of the relative powers of chlorine and bromine to dissolve gold would have required a very different series of tests, in which varying amounts of liquid chlorine and bromine, dissolved in a given amount of water, would have been revolved together in glass-stoppered bottles in the regulation water-bath for different periods of time, and made to act upon the same excess of finely-divided gold. In comparing barrel-chlorination and barrel-bromination as carried out in treating ores, the chlorine solution will probably be warmer at the start than the bromine solution, as pointed out by Dr. Rose, and be therefore liable to act more energetically than its equivalent of bromine; but that lies in the nature of the two processes. Although our paper clearly points to the fact that we confined our work to following the working-conditions of ore-treatment in revolving-barrels, a misunderstanding of our purpose would have been excluded if we had stated it in so many words in the text or in the title.

The Influence of Carbon, Phosphorus, Manganese and Sulphur on the Tensile Strength of Open-Hearth Steel.

Discussion of the Paper by Mr. H. H Campbell, (see *Trans* , xxxv., 772).

MANSFIELD MERRIMAN, Lehigh University, South Bethlehem, Pa. (communication to the Secretary*):—The formulas established by Mr. Campbell require the use of tables in order to take into account the influence of manganese on the tensile strength of steel. On examining these tables I find that the quantities given therein may be expressed by simple algebraic forms, so that formulas for tensile strength may be written which can be used without the help of tables.

Referring to the case where the carbon is determined by

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* Received August 11, 1905.

combustion, Mr. Campbell's formula for the tensile strength of acid steel in pounds per square inch is

$$40{,}000 + 1{,}000\ C + 1{,}000\ P + x\,Mn,$$

in which C and P are the amounts of carbon and phosphorus in units of 0.01 per cent., while x Mn is to be taken from his Table VII. This table is one of double entry, the arguments being the amounts of carbon and manganese. Taking Mn also as the amount of manganese in units of 0.01 per cent., I find that the values of x Mn given in this table are expressed by

$$x\,Mn = -320\ C + 8\ C\,Mn,$$

and accordingly the formula for tensile strength of acid steel becomes

$$40{,}000 + 680\ C + 1{,}000\ P + 8\ C\,Mn,$$

which may be used without referring to a table. For example, let carbon be 0.50 per cent. or $C = 50$, phosphorus be 0.05 per cent. or $P = 5$, and manganese be 0.45 per cent. or $Mn = 45$; then the tensile strength of the acid steel is 97,000 lb. per sq. inch.

For basic steel, carbon being determined by combustion, Mr. Campbell's formula for tensile strength is

$$41{,}500 + 770\ C + 1{,}000\ P + y\,Mn,$$

in which y Mn is taken from his Table XIII, according to the proportions of carbon and manganese present. For this case I find

$$y\,Mn = -2{,}700 - 120\ C + 90\ Mn + 4\ C\,Mn,$$

and hence the formula for tensile strength of basic steel becomes

$$38{,}800 + 650\ C + 1{,}000\ P + 90\ Mn + 4\ C\,Mn,$$

which may be used for direct computations. For example, let carbon be 0.30 per cent. or $C = 30$, phosphorus be 0.01 per cent. or $P = 1$, and manganese be 0.45 per cent. or $Mn = 45$; then the tensile strength of the basic steel is 68,750 lb. per sq. inch.

The last term of each of these formulas contains the product of C and Mn, and hence the formulas do not, perhaps, clearly exhibit at first sight the influence of carbon upon the tensile strength. They may, however, be written in the forms,

for acid steel, $40,000 + (680 + 8\,Mn)\,C + 1,000\,P$;
for basic steel, $38,800 + (650 + 4\,Mn)\,C + 1,000\,P + 90\,Mn$.

It is now clearly seen that each 0.01 per cent. of carbon adds to the tensile strength a number of pounds per sq. in., which is expressed by $680 + 8\,Mn$ for acid steel and by $650 + 4\,Mn$ for basic steel. Thus, if manganese is 0.50 per cent. or $Mn = 50$, then each 0.01 of carbon adds 1,080 lb per sq. in. to the strength of acid steel and 850 lb. per sq. in. to that of basic steel.

The formulas also show that each 0.01 per cent. of manganese adds to the tensile strength a number of pounds per sq. in., which is expressed by $8\,C$ for acid steel and by $90 + 4\,C$ for basic steel. Thus, if carbon is 0.30 per cent. or $C = 30$, then each 0.01 per cent. of manganese adds 240 lb. per sq. in. to the strength of acid steel and 210 lb. per sq. in. to that of basic steel.

The algebraic expression of the influence of carbon and manganese on the strength of open-hearth steel is probably only one of the important results which may be deduced from the valuable paper of Mr. Campbell, for long-continued careful records of actual facts will always deserve careful study.

The Equipment of a Laboratory for Metallurgical Chemistry in a Technical School.

Reply to Arthur Jarman's discussion of the Paper of Charles H. White (see *Trans*, xxxv., 971).

CHARLES H. WHITE, Harvard University, Cambridge, Mass. (communication to the Secretary*):—In answer to Mr. Jarman's questions I am able to say that constant use (during term-time) since 1901 has shown the new appliances in our laboratory to be very satisfactory. The draft in the hoods is sufficient to lift the fumes promptly from the baths and hot-plates; and the occasional application of stove-polish,—usually about three times a year, at the recess-periods,—so well protects all iron-work in the hoods that, up to the present time, there is very little evidence of the corroding action of acid fumes.

Iron should never be used in the construction of hoods above

* Received May 11, 1905.

the level of the hot-plates. There was at one time in this laboratory a large hood with a 30-ft. flue made of heavy galvanized iron and coated inside with asphalt paint. There were three very serious objections to it: (1) having only natural draft, the fumes were not discharged through the flue, but escaped around the doors into the laboratory; (2) it occupied much valuable space; and (3) there was a perpetual "shower" of iron-rust and paint into all uncovered analyses going on inside the hood.

The floors of the hoods in the Harvard metallurgical laboratory are of slate. When it was found that the heat must be used near enough to the slate to crack it, short pieces of scantling were fixed beneath the floors to support them, as shown in Figs. 2 and 3 of my original paper.[1] An inconspicuous crack appeared in the slate, usually on heating the baths to a high temperature for the first time, and after that no further cracking took place. The most serious objection I can find to this crack is the knowledge that it is there; and I have no doubt that these floors, as they are, will be more durable and give less annoyance than tile-covered floors. The tile surface, however, presents a neater appearance and improves the light, though my observation has been that it is almost impossible to procure tiles that have a satisfactory glaze. After only a short service the glaze is usually badly cracked. The method of setting the tiles in asphalt, suggested by Mr. Jarman, I believe would be excellent.

The sinks in our laboratory are of cast-iron and are of the simplest pattern. They are covered, inside and out, three or four times a year with asphalt paint, and so far, seem to be about as good as new. Recently, I visited a laboratory that has a small trap for each sink. Being small, the traps soon choke with rust, and are an endless expense. One large trap for the whole laboratory is more economical in both installation and maintenance, and is equally as satisfactory from sanitary considerations. While there has been no expense whatever for plumbing-repairs in our laboratory, yet we naturally expect such equipment to be short-lived, and gladly welcome any means of proved value for prolonging the life of these appliances, such, for example, as that described by Mr. Jarman in use in the sinks of the University laboratory at Sydney.

[1] *Trans.*, xxxv., 119, 121 (1905).

The Manufacture and Characteristics of Wrought-Iron.

Discussion of the paper of James P. Roe, p. 203.*

C. EDWARD STAFFORD, Chester, Pa.:—During all my business life, I have been engaged in the manufacture of Bessemer and open-hearth steels, but, during my long connection with the Shoenberger Steel Co. of Pittsburg, I had some experience in the manufacture of high-grade puddled iron for horseshoes, and in making, by Dr. Otto Wuth's process, extremely pure, low-phosphorus puddled blooms (analyzing from 0.005 to 0.01 per cent. of phosphorus and sulphur), which were melted with low-phosphorus pig-iron in acid open-hearth furnaces, to make extra locomotive fire-box steel. I have also seen the Danks puddlers in operation at different times and places, notably where they were most successful, at the Otis Steel Works, Cleveland, Ohio; then under the management of our friend, Mr. S. T. Wellman. These Danks blooms were made solely for open-hearth melting-stock, to which they were well adapted. (The unavoidable presence of bits of ore-fix imbedded in the mass of the metal always prevents the profitable manufacture of merchant iron from Danks' blooms.)

With the experience just described, I was to some degree in position to value fairly the means, methods and results of Mr. Roe's mechanical puddling from the metallurgical or technical and economic points of view, when given an opportunity by Mr. Roe to see his puddling-furnace or machine in operation in Pottstown, Pa.

Briefly, the furnace, with water-cooled bottom, is rectangular in plan, about 20 by 8 ft. in the clear, suspended by trunnions at the middle of the long sides, at a height of 17 or 18 ft. above the general level. The oscillation (65° each way from the vertical) is accomplished by geared segments (attached to the downward-projecting side or trunnion-plates) with which engage pinions driven by a reversing engine. The whole section

* Presented orally at the Washington meeting, May, 1905.

of the discharge-end of the furnace is closed by a water-cooled hinged door; in the side at this end is an opening for additions of scale or ground ore; at the receiving- or charging-end is a slag tap-hole, and on the side an attached spout into which are poured the liquid iron and oxides. The bottom and the sides to a height somewhat above the slag-line are lined with magnesite brick; above the slag-line and for the roof, firebrick are used. Fuel-oil and blast are introduced through the two trunnions and the products of combustion escape through two segmental stacks at each end of the furnace, discharging into the atmosphere at a distance of about 16 ft. measured from the trunnion on a line at right angles to the bottom of the furnace.

The cycle of operation is, briefly, as follows:—Molten cinder is run into the furnace to seal the discharge-door (which has been opened to discharge the preceding heat, and immediately closed) and to lubricate the bottom. The oxidized metalloids in the metal enter into and combine with this cinder. Molten iron direct from a blast-furnace is then poured in, followed immediately by roll-scale or easily reducible iron-ore, charged through the side-opening near the discharge-end. The furnace is then oscillated, and scale- or ore-additions are made between oscillations until sufficient has been added: the quantity varying with the percentage of metalloids in the metal. When the bath is nearly desiliconized, the greater part of the cinder is "bled" off, and additional molten cinder is added in order to lubricate the bottom and form the welding-cinder; next, roll-scale or iron-ore is added to decarburize the iron. Between the various additions, the machine is oscillated to agitate and keep the iron and cinders thoroughly and uniformly mixed. When the iron "comes to nature," it is compacted into a comparatively slag-free mass by sliding down the hearth of the machine against the ends. The discharge-door is opened; the furnace is quickly turned down; and the mass slides out by its own weight into a hydraulic squeezer of special design, and is compressed therein in the three dimensions into a squeezed slab ready for direct rolling in the blooming-mill.

Immediately following the discharge of the mass from the puddling-machine or furnace, the end-door is closed and a new cycle at once begins, as no "fixing" is necessary.

The apparatus is efficient, well adapted to the purpose, appar-

ently durable, and subject to comparatively little wear and deterioration.

The process is always under even more immediate control than in making steel by the open-hearth process. The reactions of the process are well-defined and more open to the observation of the operator, who can hasten or retard them by manipulation of the flame and furnace, and by the time, character and quantity of the additions. The iron is more thoroughly worked or wrought than is possible by manual labor in the ordinary puddling furnace.

The finished iron is more regular in its constitution than iron made by ordinary means and methods, and as free from slag. It is possible to produce regularly at will iron of a tensile strength of from 48,000 to 60,000 lb. per sq. inch. The superior character of the iron is indicated by the following mechanical tests of specimens 8 in. in length.

	Ten Strength per Sq Inch	Elongation.	Reduction of Area.
Plate Iron			
	Pounds.	Per Cent.	Per Cent
7 in. by $\frac{1}{2}$ in....	50,319	27.5	39.4
7 in. by $\frac{1}{2}$ in	52,720	28.7	48.6
Merchant Iron			
$\frac{7}{8}$ in round...	54,980	32 25	....
$\frac{15}{32}$ in. round.	54,230	33.00	. . ..

On comparing the means and methods used in ordinary hand-puddling with those employed in the Roe process, the great economies of the latter will be readily understood.

The ordinary unit of production is the puddled ball of about 180 lb., whereas the Roe squeezed slab is 4,000 lb., and readily may have twice that weight, or the same weight as a Bessemer or open-hearth steel ingot.

In ordinary puddling, the loss is from 4 to 6 per cent., and in the Bessemer and open-hearth process it varies from 5 to 9 per cent. In the Roe process, there is a gain of about 4 per cent. derived from the additions of ore-scale and cinder.

The Roe process is capable of using pig-iron having a wide

range of composition. It has successfully used irons varying in silicon from 0.3 to 3.5 per cent.; sulphur from trace to 0.35 per cent.; and phosphorus, 0.3 to 2.5 per cent. These differences in composition are taken care of by varying the additions of scale and cinder, and by manipulation of the furnace. The time of making the heat does not seem to be much affected. A 2.5-ton Roe puddling-furnace with three attendants producing 30 tons of squeezed slabs per turn of 12 hr. does it at an immense saving in labor and fuel over ordinary method of hand-puddling.

In the ordinary puddling-process, as is well known, "muck bar" is rolled from the "ball"; and when cold, it is cut into specified lengths for piles for the finishing-mill. In the Roe process, the place of the loosely-constructed, heterogeneous and expensive "piles" is taken by clean, solid and cheaper billets.

The re-heating of the solid iron-billets from the Roe process does not result in as much waste as where muck-bar piles are re-heated. A fair-sized pile will lose about 10 or 11 per cent. in an ordinary heating-furnace, while these solid iron blooms will lose only 5 or 6 per cent. Moreover, the re-heating of the solid blooms does not take as much time or fuel. These are important economies in manufacture.

In reckoning the comparative blooming-mill costs of soft steel and of Roe iron billets, it must be remembered that the croppage of the iron billets would be much less than that of steel, as the ends of the finished iron billets or slabs would have to be merely cropped off square, while with steel heavier croppage is imperative to obtain billets solid at the ends and to get rid of the segregated portion of the ingot. After blooming, the iron billets or slabs may be treated precisely the same as steel; that is, they may be rolled direct, or allowed to cool and later be re-heated for further rolling.

The low cost of Roe puddled iron, like that of steel, is largely due to intelligent dealing with large masses and tonnages by machinery; thereby displacing expensive manual labor, working slowly, irregularly and wastefully, with small units and quantities. The greatly increased production and low cost are not gained at the expense of quality. The quality is generally better.

The Roe process is a technical success, and from the brief

observation I have given it I do not see why Roe iron billets or slabs should not be made as cheaply as soft Bessemer steel billets in the same district and for the same daily output. This low cost of producing a most excellent quality of iron opens up a wide field for iron from which it cannot be driven by the competition of Bessemer and open-hearth soft steels. We know that, for many purposes, iron is preferred to steel when it can be had at the same price, and, in some important cases, where even higher prices must be paid.

The Roe mechanical puddling-process is a distinct advance in the metallurgy of iron. I am confident it will stand as an important commercial process alongside the Bessemer and open-hearth steel processes.

Dr. Charles B. Dudley, Altoona, Pa.:—Those of us who are using metals continuously cannot help noticing at the present time a distinct trend toward a return to the use of wrought-iron in place of steel in certain constructions. It is well known that, for the last 20 or 25 years, the trend has been markedly in the other direction. Wherever possible, steel has been substituted for iron; and it may be said, with all honesty, that the belief and feeling of those who have guided this change have been that the substitution of a homogeneous, well-made metal like steel, for a non-homogeneous metal like wrought-iron, which was apt to be full of flaws and bad welds, was not only wise, but clearly a step in the right direction. However, as we have obtained more experience with the use of steel (and I may say that it has apparently taken about 20 years to get this experience), we are finding that, in certain constructions, steel is not proving to be as satisfactory as we had hoped. This may be due partly to lack of knowledge, which has led us to use steel of a grade not fitted to the work; and it may be due partly to the design, since, when we change from one metal to another, it does not necessarily follow that the same construction and size of parts will give satisfactory results; and it may be due partly to workmanship, since it is not necessarily true that the two metals should be treated exactly alike. Whatever the cause, the difference in the behavior of the two metals in service, at least in certain constructions, is very clear. I am inclined to think there is a fourth

cause of this difference, perhaps more important than those already mentioned, namely, the nature of the two metals.

In order to make clear what I have in mind, it will be essential to say that the place where iron and steel behave so differently, and apparently to the advantage of the iron, is where the metal in service is subjected to bending-stresses. We have very little evidence that where the stress is that of simple tension or compression, steel is not by far the better metal; but when we come to bending-stresses we are apparently in a different field. It is perhaps not too much to say that almost every part of a structure that moves and carries a load is subjected to bending-stresses, sometimes in both directions, and sometimes in only one. A good example is a car-axle. At each revolution, the axle, almost throughout its whole length, is subjected to bending-stresses. Other examples are driving-axles, crank-pins, piston-rods (where they fasten into the cross-heads), equalizers and locomotive-frames. This list might be extended almost indefinitely.

Considering bending-stresses, it is evident that the outside fibers of a piece of metal subjected to such stresses suffer a more severe strain than the inner ones; and it is of course evident that, the conditions under which the bending-stress is applied being known, it is possible to calculate the strain in the outside fibers. This is technically known as "maximum fiber-stress." If the bending is all in one direction, the maximum fiber-stress may be in tension, or it may be in compression. If it is in both directions, the maximum fiber-stress is alternately tension and compression, and, so far as known, the two are equally disintegrating to the metal.

Coming now to actual conditions of service, in a car-axle, for example: the maximum fiber-stress allowable by calculation is from 18,000 to 20,000 lb. per sq. in. in certain parts of the axle, and from 7,000 to 10,000 or 12,000 lb. in other parts. The experience of the Pennsylvania railroad indicates that, with this maximum calculated fiber-stress, if the metal used in car-axles is steel of not above 65,000 or 70,000 lb. tensile strength, the axle will sooner or later fail in service. The method of failure is peculiar and worth a word of remark. For example, instead of the journal breaking off from the axle suddenly, through shock (as we are quite accustomed to see things break), apparently the

portion under the maximum fiber-stress begins to break without any elongation or stretch. This, of course, will be at the surface of the journal, usually at the fillet of the shoulder. A single fiber, if we may use the expression, having broken, the next fiber underneath it receives the maximum fiber-stress slightly increased, and it ultimately fails; and so on, until, after a while, there will be quite a large portion of the section of the axle broken off in this manner. Then some sudden shock breaks the rest of it, and the journal drops off. This breaking of the parts subjected to the maximum fiber-stress, a little at a time, is known as "detail-fracture," or sometimes as "progressive fracture." It is a real trouble, and occurs in many cases besides that of car-axles.

With our present knowledge of the subject, the remedy for the failure of a part through detail-fracture is twofold: (1) either increase the size of the part, which with the same loads will diminish the fiber-stress, as is clearly evident, or, (2) change the nature of the steel, so that the ratio between the calculated maximum fiber-stress and the ultimate tensile strength will be greater; that is to say, if we may trust the experience of the Pennsylvania railroad, if the maximum fiber-stress between wheels is 20,000 lb., and a steel of 65,000 or 70,000 lb. tensile strength is used, sooner or later there will be failures in the car-axles between the wheels. On the other hand, with exactly the same sizes and loads, and consequently the same maximum fiber-stress, if the steel used is from 80,000 to 85,000 lb. in tensile strength, there will be no such failures during the life of the axle.

The point to which I am leading and to which all that I have said is preliminary, is this:—Iron and steel do not behave alike, when subjected to bending-stresses. I think it is perfectly safe to say that a well-made iron car-axle, the metal of which will show in tensile strength from 48,000 to 52,000 lb. per sq. in., will stand successfully the same fiber-stress as steel of 80,000 to 85,000 lb. tensile strength. Just why this is so, I am unable to explain; but there is a very large amount of accumulated experience which seems to indicate that a metal like iron, which is believed to be a bundle of fibers, each one surrounded by slag, and which has within itself the capacity of distributing these strains, is a more reliable metal when sub-

jected to bending-stresses than a perfectly homogeneous metal like steel. This is hardly the place or the time to go into a discussion of this phase of the case; and so I close by saying that the present outlook seems to be that, if wrought-iron can be made in sufficiently large masses, so that flaws and defective welds will be eliminated, it might again become a successful rival of steel, especially if it can be made at a cost that will permit commercial competition.

Dr. Allerton S. Cushman, Washington, D. C.:—My connection with this discussion is rather indirect, because I make no claim to have had very much experience in the problems that are presented to iron and steel men, whether manufacturers or users, but I occupy the position of chemist in the Division of Tests of the Department of Agriculture, and so many complaints have reached the Department as to the lasting quality of modern steel wire, which is sold to American farmers for fencing-purposes, that the Secretary and the Assistant Secretary of Agriculture have interested themselves in the problem, and have asked me to investigate it, or at least to begin the collection of data with a view to making a thorough investigation of the whole subject.

I knew of no reason why modern steel wire should not last as long as the older wires. Inquiries among men who have had a large experience did not lead to any satisfactory source of information. Text-books on the metallurgy of iron and steel contain contradictory statements, and the question seems to be one as yet unanswered.

Several of the influential farmers' journals in the country have taken up the matter, and in every issue we are reminded that something ought to be done. Farmers complain that galvanized steel wire fences go to pieces in two or three years; and yet some of these farmers have good iron wire fences which were put up 30 years ago. I am not ready to report upon what we have done so far in any positive tone, because the work is very young.

I am very much interested in that part of Mr. Roe's paper which refers to oxidation, and more especially in Doctor Raymond's letter there quoted, which calls attention to the opinion of the late Doctor Drown. After having examined

carefully, in the laboratory, samples of iron and steel wire that had failed, and of wire that had not failed, we noticed that those which had failed contained manganese as high as 0.4 per cent. in the large majority of cases, while wires which lasted did not contain manganese at all. If, however, the solution were as simple as that it would not have been a problem, and we realized that this point would have been observed long ago. As a matter of fact it is not so simple.

We thought that perhaps the best way to begin was to get as pure iron as possible by the Goldschmidt-thermit process and commence with that, and then see if we could work out a laboratory-method of studying the problem. The first thing we did was to make laboratory-ingots with different percentages of manganese. By studying ingots of definite composition we thought we might perhaps work out a laboratory-method of determining the relative rate of oxidation.

As far as we have gone, this much seems to be true: iron which is free from manganese is not so readily oxidized by very dilute solutions of hydrogen peroxide as those irons which contain appreciable amounts of manganese. The very dilute solutions of hydrogen peroxide that we used are not unlike rain-water, that is to say—thunder-shower water. It is easy to make, in the laboratory, solutions of nitric acid, carbonic acid, etc., and thus approximate the out-door conditions to which wire is subjected by rain-water containing small amounts of hydrogen peroxide, carbonic acid, nitric acid, sulphuric acid and other constituents.

A number of samples of fence-wire have been collected from farmers. Some were in good condition, and others in extremely bad condition, after 30 years of service. We believed that the good wires would prove to contain no manganese and that the bad wires would contain much. As a matter of fact, it did not invariably turn out that way; but I think it is safe to say that, in the majority of cases, and especially with the modern steel wires made by the Bessemer process, the presence of manganese does increase the rate of oxidation; that is, manganese has something to do with it directly. With the iron wires, so far as we have gone, it does not look as though the manganese had so much to do with the matter. It naturally occurs to one that the distribution of manganese in the metal may possibly

be the cause of the trouble. If we have manganese very evenly distributed throughout the mass of the metal, electrolytic action need not necessarily be set up; but if there be unevenness in the distribution of the manganese, then electrolytic action, leading to pitting and pock-marking of the iron, may take place. All we can do is to speculate, pending a systematic investigation of the matter, which, it seems to me, has not yet been made by any one.

I have referred to Doctor Drown's opinion, cited by Dr. Raymond. He must have made an investigation of this matter; but I have not seen his published results. The Department of Agriculture has determined to find out, if possible, why these fence wires go to pieces so rapidly, and hopes that manufacturers will co-operate in discovering the reasons for the trouble noted.

R. W. RAYMOND, N. Y. City:—Dr. Drown's results were never published. They were reported in private letters, not now in my possession. I would ask Dr. Cushman how this corroded wire looked.

DR. CUSHMAN:—The wires were badly pitted or pock-marked. If the whole surface of the iron had rusted, it would not have been so bad; but in nearly every case the old iron fence-wire was badly pitted, and sometimes these pits extended nearly through, and then the wire would break. You remember that in the old days they made wire heavier than now. The increased tensile strength of steel enabled them to use less metal for the same strength, and that has something to do with it. Furthermore, exposure to the action of the elements plays an important part. To-day they twist the strands of wire, thereby forming little cups where the water is lodged, forming a rusting-point. Making every allowance, there is no doubt that modern wire is not as lasting as it should be.

I am told by men who are using steel pipe, that, as compared with iron pipe, steel pipe "pits," and there are many in this country who are discontinuing the use of steel pipes for this reason. My experience leads me to the same conclusion that Doctor Dudley has reached, that is to say, that the time is coming when perhaps a return to the older processes is going to yield a metal better suited to certain purposes than the more convenient modern processes.

J. E. Johnson, Jr.:—Did you ever make any comparison of the contents in sulphur and manganese? This may be important, because the manganese will be present as sulphide of manganese, as long as there is any sulphur to take up, and probably some of it will be in the form of sulphate.

Dr. Cushman:—I realize that the problem is complex, and that the inquiry suggested would be very interesting, and (like other collateral investigations not yet executed) must be made before a final solution can be reached. I do not think any one knows whether the action of the manganese is catalytic in its nature, or whether it is due to the mere fact that manganese oxidizes rapidly, or again, whether the action is electrolytic.

Joseph Hartshorne, Pottstown, Pa. —It is, of course, well known that the chemical composition of iron and steel has a great influence upon their resistance to corrosion. For instance, the presence of any nickel retards oxidation and a sufficient quantity will prevent it entirely. It seems very probable, therefore, that, as suggested by Dr. Cushman, manganese has a decided effect and that it is in favor of oxidation, but I do not remember any report of tests bearing directly on this point.

Other elements undoubtedly exercise considerable influence. In this connection a series of tests, made by Engineer Diegel of the German torpedo service, are important. They cover the relative corrosion of certain alloys by sea-water.[1] Among these alloys was "flusseisen," or soft steel. The results on this material show that phosphorus has a protective effect against corrosion, since the plates with high phosphorus resisted corrosion better than those low in phosphorus. They also show that there is an electrolytic action between plates of different contents of phosphorus when in contact, whereby the low phosphorus plate corrodes much faster than when isolated or in contact with plates containing like amounts of phosphorus.

The extreme probability that the presence of manganese increases the liability to corrosion, while that of phosphorus decreases it, affords a good reason why puddled iron should resist corrosion better than steel, since iron rarely contains more than a trace of the former element and usually contains very much more of the latter than is allowable in steel.

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[1] Das Verhalten einiger Metalle im Seewasser, *Stahl und Eisen*, vol. xxiv., Nos. 10 and 11, May 15 and June 1, 1904.

Like all laboratory experiments in this line, however, those just referred to, while very interesting and important, are merely indicative and not demonstrative. The samples used in such tests are not subjected to the ordinary conditions of practice, and the results obtained may or may not correspond to those obtained in practice. For instance, the samples are merely suspended in the attacking medium, such as sea-water, dilute solutions of mixed acids, hydrogen peroxide, etc., in a quiescent state, while in practice the surface is generally subjected to movement and stresses of various kinds. From this, it results that the rust is shaken off as it forms, and fresh surfaces are continually being exposed. I do not mean to assert that this action always hastens corrosion, under some circumstances it might even retard it, but merely to point out the inherent differences between the two sets of conditions.

Such experiments can show only the relative rates of corrosion of the substances investigated under the conditions given. They may indicate, perhaps very definitely, the probable rate at which the substance will corrode in practice, but cannot determine it with, say, anything like the accuracy that an analysis for phosphorus will show the capacity to resist shock. The only way in which this question can ever be settled, it seems to me, is by the collation of as many examples from actual practice as possible, preferably those in which iron and steel are used side by side under the same conditions, either intentionally for comparison or incidentally.

As examples of what I mean, I will refer to two incidents in my own experience, although many of you have probably met with the same. A Bessemer steel-works was built under my supervision in 1885, the roof and sides of which were made of corrugated iron sheets of heavy gauge. They received two coats of paint on both sides before erection, and one on the outside when in place. The sheets were put on in the latter part of 1885, blowing began in July, 1886, and ceased finally in August, 1893. Since that time most of the buildings have been entirely neglected. Extensions were erected at various times, generally after 1889, for which steel sheets of the same gauge were used and treated in the same way. The parts of the first roof immediately over the cupolas and converters were renewed twice during the eight years of running; but the rest

of it was not touched, except to repaint it once on the outside. Much of the roof and a still larger proportion of the sides will still turn water after 20 years, although they have not been painted for 11 years, and the wind has had free play with the sheets, which were never fastened if they got loose. None of the steel plates lasted over four years; and a part which was re-roofed with steel sheets in May, 1901, now requires renewal.

In 1885, a smoke-flue, made of galvanized sheet iron, was put in with the furnace of the house I then occupied, and, when I left it in 1893, it was apparently in as good condition as when new. A flue, similar to the other in every respect except that it was made of sheet steel, was put into my new house in 1893, in connection with a furnace of the same size and make, and under the same general conditions of firing, but in a drier cellar. This flue has been renewed twice in the 12 years since then, on account of having rusted out.

My experience with tin-smiths and roofers is strongly confirmatory of Dr. Raymond's. There is a general complaint that the galvanized and tin sheets of the present do not last anything like as long as those made 25 or 30 years ago. The old men, who have had experience with both kinds, say that the present sheets last only a fourth or a fifth as long as the old ones. Only a few attribute this to the old sheets being made of iron and the present ones of steel; but, on the other hand, few of them know this fact or appreciate what it means.

I was very glad to hear Dr. Dudley, whose opportunities for investigation and observation are unsurpassed, indorse the remark I made this morning in announcing this discussion. My own investigations had led me to believe that iron was the better material for many of the purposes to which steel is now applied; and it seemed to me that the decided trend of opinion, not only among tradesmen, but also among engineers and investigators, was in the same direction. If this opinion be warranted by the facts, as now, more than ever, I think it is, then the use of iron must largely increase in the near future. Much more so must this be the case if, as stated by Mr. Stafford, puddled iron can be produced by the Roe process as cheaply as steel is now produced. My own knowledge of the Roe process leads me to agree with Mr. Stafford.

N. B. Wittman, Philadelphia, Pa.:—Several years ago, during the latter 80's and up to the early 90's, the substitution of both Bessemer and open-hearth soft steel, for purposes previously served by wrought-iron, caused many capable observers to hold the view that wrought-iron would soon fill but an unimportant part in metallurgy. In looking over the *Directory of the American Iron and Steel Association*, the rapid decline in the number of active puddling-furnaces reported up to the year 1898 will be noted. The entire withdrawal of such important firms as the Carnegie, Cambria Steel, Jones & Laughlins, and others, from puddling, was responsible for the greater part of the decline. Since 1898, this movement, on the whole, has been checked; and a study of the *Directory* will show a very important increase in the number of active puddling-furnaces in certain localities, and among old established firms, who have held to iron for certain purposes irrespective of locality. In eastern Pennsylvania, to-day, many new puddling-furnaces are being built; and, even in Pittsburg, many of the firms which have held to the iron-business are larger puddlers than in 1898.

The superior shop-working qualities of soft steel, together with attractive physical tests and analyses, naturally commend it, but the test of use unquestionably shows that, for many purposes, it is not so durable as iron. Several years ago the iron nail was practically driven out of the market by the cut-steel nail. After a time it was found that structures nailed with steel nails would not hold because the nails rusted off under the heads very rapidly. It was also found that, for scaffolding and similar purposes, cut-steel nails had less holding-power than cut-iron nails; and a demand has again sprung up for the cut-iron nail. The tonnage of the latter at present produced is still small, but it is large compared with what it was several years ago; and it is still growing.

For wrought-iron pipe, notwithstanding the higher cost of production, the demand has been sufficient to employ several important works exclusively for the manufacture of this product. For boiler-tubes, steel has not been satisfactory, and although almost all new stationary boilers are equipped with steel tubes (principally because they cost about $1 per horse-power less, and are preferred for easy working), the general experience has been that, with most waters, they are not so durable as the

charcoal-iron; and the greater number of locomotive tubes are made from charcoal-iron skelp. In this connection I know of an important steel-manufacturer, naturally having no prejudice in favor of iron, who will not allow a steel tube in the boilers, or a steel sheet on the roofs of his buildings.

Another important concern, well known as a producer of steel for special purposes, has not been able to make steel suitable for stay-bolts, and is increasing its iron-puddling capacity at this time, principally for the purpose of making stay-bolt iron.

In view of Mr. Roe's admirable statement concerning the structure of iron, I believe that, if we could divest ourselves of prejudice and forget that we have ever regarded ourselves as iron-men or as steel-men, and would use our metallurgical knowledge only in forming opinions, we would, in view of the stable nature of the silicate of protoxide of iron which envelops the grains of iron, and in view of the rougher surface which results from it, conclude that, for holding protecting material and for resisting corrosive influences, iron is superior to steel; while, for deep-stamping purposes, requiring equal strength in all directions, and for purposes in which high tensile strength and elasticity are required, or for any purposes in which temper is essential, steel is obviously superior to iron. If this view is correct, the importance of Mr. Roe's puddling-process is apparent. It embodies every element of successful puddling, and is capable of the same scale of operation as either of the steel-processes. The ordinary puddling-process is the only metallurgical process in practical use to-day which can successfully and economically deal with sulphur. This advantage is retained in the Roe process, in addition to which the allowable silicon- and phosphorus-content of the initial pig-iron permit a wide variation. This renders available fuel, ore and limestone, which would be unsuitable, or at least not economical, for producing metal to be used by the Bessemer and open-hearth processes.

As Mr. Stafford has pointed out, the possibilities of economical production through heavy tonnage are the same as in the steel-processes. In view of the probability that the future increase in tonnage of iron and steel will be largely in the lighter products, there is a need in these lines for material which will better resist destruction than mild steel has done.

JAMES P. ROE, Pottstown, Pa. (communication to the Secretary*):—It has been very gratifying to me to note the interest in the discussion of my paper. In a crude way many of us know a good deal about the properties of iron and steel to which Dr. Dudley refers, but only a trained observer such as he is can present the definite data needed to determine the selection and use of suitable metals for different purposes.

Steel has permanently displaced iron for many purposes; but in some instances it has not proved satisfactory. Such instances are becoming more frequent, and many makers of finished material would welcome a change back to iron.

The investigation of the corrosion of iron and steel fencing-wire that is being made by the Department of Agriculture will have far-reaching economic results. In iron, the manganese exists as oxides in the slag, and therefore is not subject to further oxidation; in properly worked iron this slag is distributed with reasonable uniformity;—that is, only such slag is present as envelopes the original grains, being reduced somewhat in volume by subsequent work; in such a condition it offers its greatest resistance to corrosion. When an undue quantity of slag is present in pockets or laminations, it is fragile, cracks off readily and possesses little protective value. Moreover, some samples for analysis might be taken by chance at points where pockets of slag exist; in which case the determinations would show a relatively high manganese content. On the other hand, the manganese in steel exists as metal held loosely as an alloy, a condition favorable to electrolytic action, especially if the manganese is unevenly distributed.

Mr. Hartshorne's remarks in regard to presence of phosphorus in iron increasing its resistance to corrosion is confirmed by my own experience in the relative corrosion of irons containing high and low phosphorus.

Mr. Wittman's reference to the increase in the number of active puddling-furnaces in the United States is important, since it represents an increased demand for iron at a price materially higher than that of steel. The same condition exists in Germany, France and England, and I am advised that the supply of puddled iron abroad does not meet the demand.

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* Received July 31, 1905.

TAYLOR ALLDERDICE, Pittsburg, Pa. (communication to the Secretary*) :—In comparing the properties of wrought-iron and steel, Mr. Roe claims superior advantages for iron in respect to oxidation and welding qualities. Narrowing the subject to the manufacture of pipe, the long experience of the National Tube Company in the making and handling of both materials may be of interest.

Modern Bessemer pipe-steel approaches the nature of wrought-iron closer than any other class of material. As now made, it possesses advantages over iron in ductility, uniformity and in welding qualities. The loss due to defective material in the pipe-mills is about one-half on steel compared to what it is with wrought-iron. The average butt-weld with steel has been found to be stronger than the transverse strength of the iron *unwelded.* This, together with the superior strength and finish of steel, has greatly widened the field for tubular goods in recent years.

Manufacturers of bedsteads and electric conduits report that failure of steel pipe due to imperfect welding is quite insignificant. Since all the pipe is bent cold, this test is perhaps the best practical one of the weld. The following letters, representing records of about 90 per cent. of the pipe bent in the United States for electric conduits, bear out our general experience on the reliability of the welded seam in steel-pipe :—

DEAR SIR :—

We beg to acknowledge receipt of your inquiry regarding our experience in bending soft steel-pipe, such as furnished by you to us for conduit purposes, and take pleasure in stating in reply that the pipe furnished bends perfectly. We have used this pipe for a number of years and are constantly making bends of all kinds on sizes from ½ to 3 inches. Thousands upon thousands of elbows are being made by us on our elbow-machine at the factory every month, and the loss due to splitting of the seam is so infinitesimal that we abandoned a long time ago to keep any record of it. We run for a month at times without a single one length opening at the seam The radius to which this material is bent varies according to the size of the pipe, but the ½-in. pipe when made into elbows is bent to a radius of about 4 inches.

In addition to this we have seen a great deal of this pipe bent cold on the job without any appearance of opening—bent into any shape and form by the workmen who install the pipe, and we can state positively that we have had no complaint for several years, at least, of any length of pipe opening at the seam under these conditions. Very truly yours,

AMERICAN CIRCULAR LOOM COMPANY,
(S) A. T. CLARK, *Treasurer.*

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* Received August 1, 1905.

DEAR SIR :—

Answering your inquiry as to our experience in bending soft steel-pipe, would say that we make at our factory anywhere from 15,000 to 20,000 bends per month, the sizes of pipe ranging from ½ to 3 in. inclusive.

In the above quantity we rarely find as many as 25 bends that will open in the seam—in fact, there have been some months when we did not have over six.

These bends are made cold, and are bent to as short a radius as 4½ in. in the smaller sizes.

Very truly yours,

SAFETY-ARMORITE CONDUIT CO.,

(S) ROBT. GARLAND, *Treasurer.*

As to oxidation: Mr. Roe has a preparatory word to say in explanation of why iron should be better protected from corrosive elements than steel. Each grain or cluster of grains is supposed to be surrounded by an "envelope of cinder" having greater resisting power than the iron. Cross-sectional enlarged photographs of wrought-iron which I have seen do not appear to show the cinder so distributed. On the contrary, the strings and layers of cinder seem to be rather "enveloped or surrounded" by iron, and in this position can hardly afford much protection to the metal.

The question of corrosion is one which has had the attention of our engineers and chemists for some time, in connection with which considerable data have been collected. Laboratory tests were made for some years with a view to comparing both materials under corrosive agencies common in practice and to obtain relative losses in weight under such conditions. The tests conducted by the U. S. Navy Department furnish interesting data on this point. As the original report is now out of print we have prepared an abstract of these results, which those interested may obtain by writing the National Tube Company, Pittsburg, Pa. Such tests show that some grades of iron lose less and some more than soft steel, the difference being within 10 per cent. one way or the other. The effect of change in surroundings is very marked, and teaches caution in drawing conclusions from service-tests where conditions are complicated and liable to local changes.

The question of pitting has been investigated under working-conditions where it seemed reasonably certain that both materials were subject to the same conditions. For instance, iron and steel tubes purposely placed in yard-engines together, show, after three or four years, that the tendency to pit is about equal.

The depth of pitting in steel seems to be in some way connected with the finish of the surface; a matter which is under further investigation. We frequently have cases of iron couplings on steel-pipe which show practically the same corrosion, depending on how active the surrounding solutions were.

A case in point has recently come up, where an extra strong 3-in. pressure-line, made up of iron and steel lengths, showed serious internal pitting in places after one year's service. It happened this time that the leak occurred in the iron section. Details of this case with a photograph of the pitted wrought-iron pipe have already been published.[1]

In view of such evidence, it looks as though Mr. Roe has exaggerated the difference between iron and steel to the prejudice of the latter. Iron appears to have at present slightly better initial protection against these destructive agencies than steel and, therefore, has a somewhat better appearance under oxidizing influences for a short period. This, however, is misleading, as experience has shown but little difference in the ultimate results. It is not uncommon to find on examining such cases that the corroded pipe presumed to be steel turns out to be iron. This shows what an amount of prejudice exists in some minds on this question.

After nearly 20 years' experience with these materials in the manufacture of pipe, the results lead us to believe that the time is not far distant when the demand for soft steel-pipe will force us to abandon the manufacture of wrought-iron entirely.

The Classification of Coals.

A discussion of the paper of Marius R. Campbell, p. 324.

Dr. Persifor Frazer, Philadelphia, Pa. (communication to the Secretary):* Mr. Campbell's very interesting contribution, after complimentary mention, finally decides against the acceptance of the classification proposed by me in a paper bearing the same title and read at the Wilkes-Barre meeting, May, 1877.[2] That paper was written primarily for the Second Geological

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[1] *Engineering Record*, June 10, 1905, p. 654.

* Received January 9, 1906.

[2] *Trans.*, vi., 430 (1877–8).

Survey of Pennsylvania, then three years in progress, and chiefly to give definite limitation to the four rather vague classes into which H. D. Rogers had divided the coals of Pennsylvania, which classes were used by Pennsylvania coal producers and coal consumers; namely, anthracite, semi-anthracite, semi-bituminous and bituminous. It was also my aim to point out the futility for classification of taking into account any other characteristics of a coal than those essential to its existence as a fuel, *i.e.*, its combustible constituents. The absurdity of considering "ash" as a factor in classifying a coal was illustrated by an analysis of the Hudson River slates, showing that if the whole rock (of which the volatile hydrocarbons formed only 3 per cent.) were considered as a slaty coal, it would come within H. D. Rogers' definition of a "hard dry anthracite;" whereas, if the combustible matter were first extracted from the inert rock and separately analysed, it would prove to be one of the most highly bituminous coals, with 62.5 per cent. of fixed carbon and 37.5 of volatile hydrocarbons.

In the same paper, I emphasized the importance of separating the water from the volatile combustible matter before attempting the calculation of a fuel ratio and subsequent classification. That this subtraction was not embodied in any of my tables was because there were no data from which to obtain it.

Shortly before 1877, it appeared from interesting experiments in Austria that, even at ordinary pressure and temperature, bituminous coals exposed to the atmosphere suffered rapid and notable losses of their volatile combustible matter.

The attempt to differentiate lignite from bituminous coals through their respective percentages of water would result in contradictions of the same kind; certain exposed coals becoming lignites after a rainy season and bituminous after a drought. Unessential constituents (or impurities) are incommensurable with essential, and are of no more use in defining kinds of coa[l] than weight would be in defining mental images.

Mr. Campbell thinks my proposition for giving definite meanings to the four terms already in use in Pennsylvania failed as a basis for a general classification of coals (1) in grouping all the coals with a fuel-ratio of 5 or less into a single class; (2) in making no provision for lignite.

As to the first objection, it might be made with equal justic[e]

to the recognition of the groups of oxides and oxygen salts in Dana's, or of silicates in Albin Weisbach's division of minerals. But the occurrence of a great preponderance of instances of a given phenomenon in a certain restricted part of an accepted scale is not *per se* a reason for discarding the scale for general classification, although it may involve the necessity of a sub-classification for this overcrowded portion.

At the outset of any attempt to arrange objects in systems the purpose of the arrangement must be clearly understood. If it be for practical use in commerce, the refined methods of research will always be inappropriate. On the other hand, if it be desired to create definite species or varieties of the objects, no other than the most delicate methods can be employed. First, then, it is necessary to determine what sort of classification is applicable to a substance like coal.

It is superfluous to say that coal is seldom, if ever, a definite mineral, but usually such a mixture of substances as used to incense that prince of determinative mineralogists, Herr Wappler, the chief of the mineral salesroom of the Mining Academy in Freiberg, Saxony, 40 years ago. When such a mixture was brought to him as a mineral with a new name, he would utter in a tone of repugnance the single word, *Zeug!* (Stuff!).

If coals be variable mixtures of combustible and incombustible materials, valuable only for their content of the former, the application of methods of ultimate research for classifying them is not less useless (and much more difficult) than the determination of the mineral species of stones used for ballast. Whatever method be used should exclude all properties but those which are essential to the material as coal; and, since there can be no possibility of the absolute individuality of a substance which results from ever-changing conditions of formation, the only essential character which can be utilized for classification of coal would seem to be that of its combustible components. Hence, not only does a fuel-value of some kind offer the best means of classifying coals, but any analysis, even though partial or "proximate," which gives each class a distinctive value, should suffice for the purpose.

Since we are dealing with variable mixtures, incapable of classification in a strictly scientific sense as species or varieties,

what is needed is a ready means of distinguishing differences by the eye and touch, aided in certain cases by a few of the most elementary tests to ascertain the specific gravity, friability, manner of burning, method of coking, volume of water-vapor, of hydrocarbons, etc.

Mr. Campbell, speaking of my effort to define the scheme already proposed by H. D. Rogers and universally adopted in Pennsylvania (and, so far as I know, thoughout the United States), says: "The selection of the name 'semi-bituminous' was unfortunate." I perfectly agree with him; but this was not my selection. The chief of the First Geological Survey of Pennsylvania introduced the term, and in trying to co-ordinate it with the three others which he had adopted, created classes which overlapped each other.

I repeat that my answer to Mr. Campbell's first objection to the proximate-analysis-fuel-ratio system (*i.e.*, that it groups a largely preponderant number of bituminous coals in the class 5 to 0, while the less numerous classes range from 100 to 5) is, that the objection is not valid as against a classification, though additional means for differentiating the members of the over-crowded class are required. The classification was intended principally for Pennsylvania, though applicable elsewhere.

To his second and last objection, that no provision is made for lignite in my scheme, I reply that none is needed, even if it were possible (as it is not) to separate lignite from bituminous coal. There is an insensible gradation from lignite through brown-coal to bituminous, and thence through all manner of variations ultimately to hard dry anthracite and graphite; and no single division has any greater value than one of the arbitrary divisions of the rays of the spectrum designated by the name of a special color. It may be doubted whether the reasons are well founded which have led Mr. Campbell to conclude that my system, and several of his own, are inadequate; though it must be conceded that the classification in Table VI. has at least one advantage mentioned below over all the others; its vulnerable point being the inclusion of "hydrogen in the water."

Beginning with Table I. of his paper, in which he has applied my system to the Government collection of 56 coals from various parts of the United States, he remarks that in the

upper part of the column (where the quotients of the fixed carbon, divided by the volatile hydrocarbon, represent large numbers) the differentiation of anthracite from semi-bituminous is sharp, but in the lower part of the column (where these quotients are smaller numbers) there is great confusion,—two samples of Pittsburg coal standing 24 and 36 in the list. The two quotients or fuel-ratios referred to are 1.49 and 1.25 respectively, and the interval between them is only 0.12 per cent., yet within this compass 12 coals have been placed with an average consecutive difference of but one hundredth of 1 per cent.! Quantities as trivial as this might easily occur from casual variations in the vegetation from which the coal was formed, so trifling that no dissimilarity from the adjoining coal could be noted; or from the unavoidable error which must accompany even the most careful sampling; or from physical and chemical changes in the coal in the intervals between two analyses. To such refinements in separation no method of classification is adapted.

On purely theoretical grounds (C', representing the carbon in combination with hydrogen, C, the uncombined or "fixed" carbon, and H, the hydrogen in the hydrocarbon) the ratio $(C + C') - H$ can lead to no more accurate results than the ratio, $C - HC'$. Any of the sources of error just alluded to will vitiate the natural sequence obtained by analysis in one expression as much as in the other. The ratio between a dividend and a divisor will not be made more constant or valuable by splitting the divisor into two factors, one of which becomes the new divisor, while the other is added to the old dividend for a new dividend.

Mr. Campbell is of the opinion that in Table VI., where the total carbon (*i.e.*, the fixed carbon plus that combined with the hydrogen in the volatile combustible matter) is divided by the hydrogen in the volatile combustible as well as that in the water, an almost ideal classification is obtained. The hydrogen in the water being represented by H', the formula becomes $(C + C) \div (H + H')$.

The amounts of water retained by different samples of the same air-dried coal will depend upon variations in physical condition not always possible to ascertain; and the greater weight of hydrogen in any such sample, obtained by adding to its com-

bustible hydrogen that combined in its mechanically entangled water, must necessarily lower the quotient or fuel-ratio of the coal, and thus separate it from other samples with which, but for this hygroscopic characteristic, it would be closely associated. The recognition of occluded water as a factor at all in estimating the fuel-ratio, is an abandonment of the principle of confining the definition to the essential (*i.e.*, the combustible) characteristics of the coal. For although it is very probable that the water vapor is dissociated, and that both of its constituents enter into combinations during combustion, yet the loss of calorific effect involved in these reactions, through the expenditure of energy in overcoming specific and latent heat and chemical affinity, must exclude its hydrogen from consideration as a fuel.

Mr. Campbell does not say definitely, in his explanation of Table VI., that the hydrogen in the water has been used in calculating the carbon-hydrogen ratio; but in two or three calculations his results are obtained by dividing the total hydrogen of Table IV. into the total carbon of Table V.

However, this assumption is not always exactly verified. Thus, for "West Va., No. 1," of which the total hydrogen-value (Table IV.) is 5.67, and the total-carbon percentage (Table V.) 84.45, Mr. Campbell's ratio in Table VI. is 14.7, whereas, apparently, it should be 14.89 (or 14.9).

If any criticism can be made of these valuable tables, it is that their purport is not stated with sufficient fullness in either text or title.

Without pretending to exhaust all the extremely interesting aspects which an examination of them reveals, it appears at once that the main reason why the divisions in Table VI. are more satisfactory than the other tables is because the divisors (the weights of hydrogen in the volatile combustible matter and in the hygroscopic water) being smaller numbers, and the dividends (the weights of the fixed carbon with those of the hydrocarbons added) larger, the quotients, and therefore the figures representing the gradations, are also larger, and will accommodate more members of a series.

For instance, the carbon-hydrogen ratio of the brown lignite, "Texas, No. 1" (9.4), at the bottom of his scale, is less than one integer smaller than the carbon-hydrocarbon ratio

for anthracite, Penna., No. 3 (10.22), at the very top of my scale of classification.

Mr. Campbell's system has also a manifest advantage over mine in dealing with the highly bituminous coals and lignites containing little or no uncombined carbon; for he still obtains a measurable ratio by splitting up the compound (of which the weight was my divisor, with nothing to divide) and making its heavy component, carbon, the dividend—thus getting a whole number for his quotient.

While congratulating Mr. Campbell on the painstaking work which has made his ingenious improvement on the fuel-ratio system possible, and sharing with him both the hope and the belief that future and more extensive investigation will lead to still further improvements and increase its value, I doubt whether the twelve groups indicated in Table VII. will ever be firmly established, or would assist either the scientific or the practical man if they were.

Nor does it seem advisable to call the determination of two out of a number of elements always present in coals an "ultimate analysis." In fact, such a determination is not much less "proximate" than the method employed by the Second Geological Survey of Pennsylvania, *et al.* It may well be that other factors than the percentage weights of carbon and hydrogen will some day furnish the means of a further differentiation of lignites, brown coals, peats, and cannel coals; as, for instance, the physical states in which they occur.

In following the figures of Mr. Campbell's six tables, along the same line from one table to another, it is very interesting to note how curiously the changes of sequence follow the changes of basis of classification. As these tables are spread out over eleven pages in his paper, I have combined them in six parallel columns on one page, for better comparison.

In the symbols at the head of the columns, C represents uncombined (or fixed) carbon; C′, carbon combined with hydrogen; H, hydrogen combined in the volatile hydrocarbons; and H′, that in the water. The calorific value is in British thermal units. The numbers in the left-hand column are those given by Mr. Campbell to the 56 coals from various States, which formed the material for his experiment, in the order in which they arranged themselves by my classification of fuel-ratio.

They begin with the hard anthracite and end with a Texas brown lignite: the first and highest fuel-ratio (No. 1) being 10.22, and the last and lowest (No. 56), 0.68.

The coals in the other columns are designated by their places in the first or left-hand column, so that the extent of their displacement by reason of another system of classification is at once seen.

In all the tables the values decrease in descending from anthracite to bituminous, except in Table IV. (hydrogen), where, of course, they increase.

There is a fair agreement of data in Tables I., II., IV., V., and VI. in the upper parts, but not in Table III., whence we learn the useful lesson of the great calorific power of the Pocahontas coals, which fill the first three places at the head of this column; which also contains, among its first seventeen numbers, all of the twelve West Virginia coals which were examined.

TABLE I.—*Comparison of Sequences in Tables I. to VI., inclusive, of Marius R. Campbell's Classification of Coals.*

I.	II.	III	IV.	V.	VI.
$\frac{C}{HC'}$.	C.	Calorific Value.	H + H'.	C + C'.	$\frac{C + C'}{H + H'}$.
1	1	6	1	1	1
2	2	5	2	6	2
3	3	4	4	5	4
4	4	10	3	3	3
5	5	8	7	2	5
6	6	15	8	4	7
7	7	9	9	10	9
8	8	11	5	7	8
9	9	12	6	8	6
10	10	3	10	9	10
11	11	13	11	15	11
12	12	7	13	11	13
13	15	14	12	13	15
14	13	16	20	14	12
15	14	2	15	16	14
16	16	24	14	12	16
17	18	36	32	24	24
18	19	21	16	18	21
19	21	1	24	36	32
20	20	19	17	23	19
21	24	18	21	19	20
22	17	30	33	21	18
23	23	23	19	22	36
24	22	32	30	32	30
25	30	22	36	34	33
26	27	53	18	30	22
27	25	20	27	53	23
28	26	34	41	42	17
29	36	27	25	33	27
30	32	33	51	20	25
31	33	42	22	27	30
32	34	38	26	25	34
33	35	35	39	54	42
34	29	17	49	38	38
35	42	25	23	17	35
36	38	44	55	44	53
37	41	54	35	35	44
38	31	43	38	43	26
39	28	52	28	41	43
40	37	48	52	48	54
41	43	37	40	52	48
42	39	41	48	26	52
43	52	26	31	37	37
44	48	29	37	46	28
45	45	46	44	45	46
46	53	45	43	29	39
47	47	47	42	47	45
48	46	28	46	28	29
49	44	31	54	31	31
50	54	39	47	39	47
51	40	40	34	40	51
52	51	55	45	51	40
53	49	56	29	56	55
54	50	51	50	50	49
55	55	50	53	55	50
56	56	49	56	49	56

The Commercial Value of Coal-Mine Sampling.

A Discussion of the Paper of Marius R Campbell, p. 341.

Mr. A. Bement, Chicago, Ill. (communication to the Secretary*):—Mr. Campbell, in proposing his method of sampling coal-seams, has rendered an important service in insisting on the presentation of an adequate history of the sample; and it is to be hoped that his suggestion will meet with further recommendation. In my opinion it is fully as important that a complete description of the sample and the conditions surrounding its taking be given, as the results of the analysis itself; and if such should become standard practice, coal-analysis would assume greater value. As it is, the published data are very confusing, and only to an extremely small extent are they really useful.

The method suggested by Mr. Campbell, however, cannot have a general application; for example, in the Eastern Interior coal-basin, particularly at the present time, the output consists largely in grades other than mine-run, which in Illinois, for the year 1905, was only about 24 per cent. of the total product; and inasmuch as Mr. Campbell's method of sampling cannot give values for any other grade than mine-run, my contention that, at best, it can have but a limited application, is apparent. To illustrate the argument, there are two coal-seams, with the characteristics of which I am particularly familiar; each seam, as it lies in the ground, contains almost exactly 10 per cent. of ash; the lump coal from one of these seams ranges from 10 to 11 per cent. of ash, but from the other seam it does not average more than 6 per cent., although, as before mentioned, the average percentage of ash in the full seam is the same for each case.

A careful and proper sampling of coal-seams, to be followed by analysis, is to be commended in connection with all investigation; in fact, it should precede any careful study. A serious error, however, may be made in attempting to use such results to set values on the product as shipped or received. The only

* Received January 22, 1906.

way that proper values can be obtained in such cases is to sample and analyze the coal as loaded or received, which, of course, will require the averaging of a large number of samples. In those cases in which the entire output is shipped as mine-run, the method proposed by Mr. Campbell certainly affords a ready means by which an approximate value may be obtained, although there is very serious danger in assuming that partings and other impurities are excluded to the extent that may be claimed.

The Use of High Percentages of Fine Ore in a Charcoal Blast-Furnace.

Discussion of the paper of Harry R. Hall, p. 360.

R. H. SWEETSER, Sault Ste. Marie, Ont. (communication to the Secretary*):—The recent work of furnace No. 1 of The Algoma Steel Co., at Sault Ste. Marie, Ontario, using for fuel, first all charcoal, then a mixture of charcoal and coke, and finally all coke, upsets the estimates given by Mr. Hall in the last two paragraphs of his interesting paper. Furnace No. 1 was built for a charcoal-furnace, and it was run on charcoal fuel from March 6 until July 9, 1905; then, for a week, a mixture of charcoal and coke was used, and, since then, coke alone has been the only fuel.

It is to be regretted that at no time, during the run on charcoal, was there enough charcoal on hand and "in sight" to warrant blowing the furnace as hard as it should have been blown. During April and May the supply of charcoal limited the amount of blast to about 8,000 cu. ft. of air per min.; in June, to about 8,900 cubic feet. For a few days in July about 10,000 cu. ft. were blown, and then the maximum daily output, 173 tons (2,240 lb.), was reached. At all times the quality of the charcoal was poor, having been made from wood cut from three to four years before. Doubtless this furnace could have produced 200 tons of iron per day, even with this quality of charcoal, provided the supply had been sufficient; and with

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* Received October 31, 1905.

good charcoal I see no reason why it could not make as much iron per day as it has made with coke.

During the one week of using a mixture of charcoal and coke, the changes in quantity of blast and composition of the slag followed each other so closely that no single condition could last long on the furnace. The results were good, and the pig-iron was about the same in quality as that made during the best week with charcoal alone. The maximum daily output was 175 tons of standard Bessemer pig-iron.

Since July 16, 1905, the coke has been used exclusively and the supply has been plentiful. Because coke requires at least 50 per cent. more air than charcoal does, the quantity of blast has been much increased, and the furnace has been blown nearly to its limit. During September, the quantity of blast was about 19,600 cu. ft. per min., as measured by piston-displacement. The average composition of the pig-iron for the month was, silicon 1.64 and sulphur 0.032 per cent. The maximum daily output was 218 tons; the best three daily averages, for periods of one week each, were 196, 198 and 203 tons respectively. The daily average from September 1–15 was 190 tons. These figures agree fairly well with Mr. Hall's estimate for the product of a charcoal-furnace having a hearth 8.5 ft. in diameter (furnace No 1 is 70 ft. by 13.5 ft. by 8 5 hearth); yet this quantity is made in a coke-furnace.

According to Mr. Hall's estimate, it is doubtful if this same furnace could make from 25 to 33 per cent. more charcoal-iron than it has made coke-iron, since this would mean a daily product of from 240 to 260 tons, and a maximum of from 270 to 290 tons. The cubic capacity of the furnace is only 6,119 cu. ft., and, while making 200 tons per day, the stock passes through in less than six hours. Still, it would take only about 16,000 cu. ft. of blast per min. to make 260 tons of charcoal-iron, and the amount now used on coke is 19,000 cubic feet. Therefore, the results obtained at Sault Ste. Marie show that either one or the other of Mr. Hall's estimates should be modified; also that the largest charcoal-furnace in the world has been so constructed that it has given excellent results with either charcoal or coke.

The Constitution of Mattes Produced in Copper-Smelting.

A Discussion of the Paper by Allan Gibb and R. C. Philp, p. 665.

EDWARD KELLER, Baltimore, Md. (communication to the Secretary*) :—The authors of this paper are to be commended for their industry and congratulated upon the many interesting results which were the fruit of their researches. While thoroughness has marked their work in general, yet on a few points in particular they have touched but lightly, for which reason, it would appear to me, they have hit wide of the mark in their respective conclusions.

The work alluded to pertains chiefly to the occurrence of magnetic iron oxide (ferroso-ferric oxide) in copper-mattes. Because the authors find that the magnetic residue, left by the dissolved sulphides, varies largely in quantity according to the strength of nitric acid used (with potassium chlorate) in dissolving the mattes, they conclude :—

"It appears, therefore, that the ferroso-ferric oxide is the result of precipitation by the oxidizing agent, rather than an original constituent of the matte"

In this part of their investigation, Messrs. Gibb and Philp have ignored some well-established data. In the first place, they have overlooked the fact that there are mattes which are strongly magnetic and others which scarcely show any magnetic property. There is nothing in their work tending to explain this variation. They seem to have tested none of their products for magnetism. Secondly, they have overlooked the fact that magnetic iron oxide probably exists in all ore-charges in the copper-matting furnaces, and, under the given conditions, that this oxide is very difficult to reduce and to combine with silica to form slag. Thirdly, they pay no attention to the varying specific gravity of the several grades of copper-matte, which may exceed, equal, or fall below that of the magnetic oxide. These are essential points which, I believe, clearly in-

* Received February 7, 1906.

dicate the great probability that magnetic oxide must enter into such mattes as have an equal or a lower specific gravity than its own. I have corroborated this conclusion by analytical results, having found low-grade mattes, from reverberatory furnaces, to be strongly magnetic and to contain a considerable percentage of magnetic oxide, while high-grade mattes of the same origin were non-magnetic and showed very little magnetic oxide;—the latter, in such cases, remaining with the slags. Low-grade mattes which are non-magnetic yield no magnetic oxide, for which no reason is given by the authors' theories.

The conclusion of Messrs. Gibb and Philp, that ferroso-ferric oxide is formed from iron proto-sulphide by the oxidation with strongest nitric acid and potassium chlorate, is not only very much against "*das chemische Gefühl*," but also contrary to all chemical precedent. These reagents convert many metals into their peroxides, and it seems incredible that the readily oxidizable iron protoxide could pass through their solution unoxidized, and be precipitated as a crystalline ferrous compound, at what might be called ordinary temperature.

While I agree with the authors that magnetic oxide probably plays no part in the chemical constitution of the mattes (*i.e.*, the sulphides), yet I know of no data to prove that the oxide was not dissolved in the sulphides in their molten state and segregated upon their solidification. Be that as it may, the authors' statement that the magnetic oxide derived as a residue from mattes shows different solubility in acids from that of other forms of magnetic oxide produced at high temperature, may be more rationally explained by the assumption that they differ in character of molecular aggregation, than by the assumption that one of them is precipitated by liquid oxidizing agents.

What the authors have established regarding the condition of excessive iron in mattes is most interesting. They show that it is not present in chemical combination with its proto-sulphide, or in any visible form as metallic iron, but that the iron proto-sulphide is capable of retaining the metal in solid solution to the extent of 24 per cent. It would be valuable to know if this solution of sulphide and metal is magnetic. I have found mattes with excessive iron to be non-magnetic.

The discovery of the state of solid solution may, in a way, explain the absence of the magnetic property of the metal. The condition of solid solution implies that the iron is not in the ordinary crystalline form, but rather in an allotropic, amorphous modification.

INDEX.

(See "ERRATA" at the end of this Index)

[NOTE.—In this Index the names of authors of papers are printed in small capitals, and the titles of papers in italics References to papers expressly treating of the subject named are likewise in italics, and casual notices, giving but little information, are usually indicated by bracketed page-numbers The titles of papers presented, but not printed in this volume, are followed by bracketed page-numbers only.]

ERRATA.

Page.	Line.	
155	29	For "Joachimstahl" read "Joachimsthal."
215	Foot-note [2].	For "May, 1892" read "May, 1902."
216	21	For "ack-screw" read "jack-screw."

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